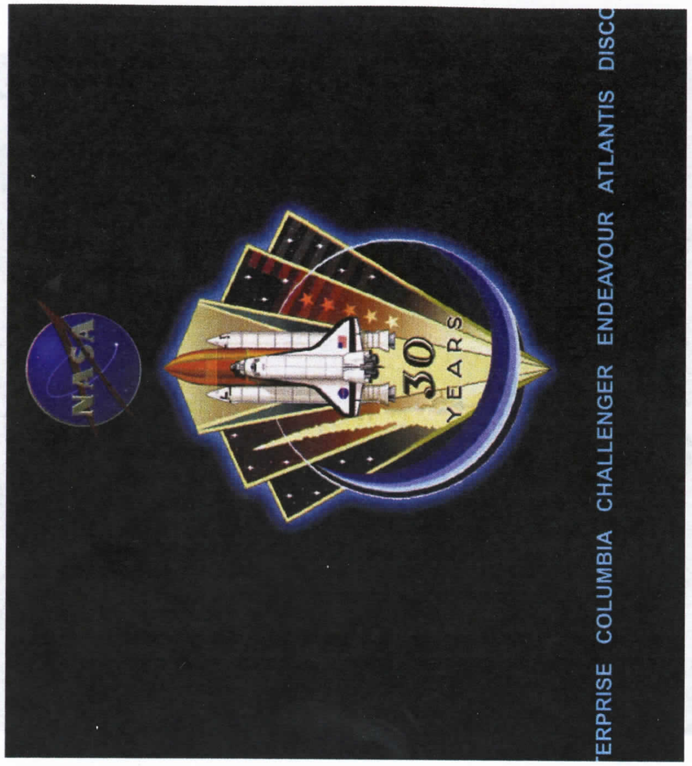
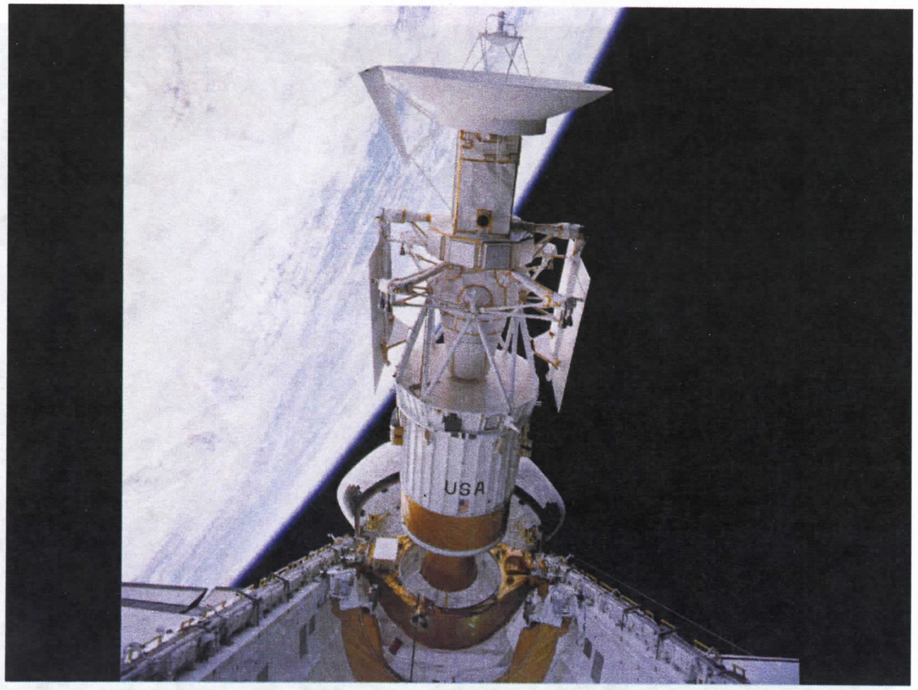
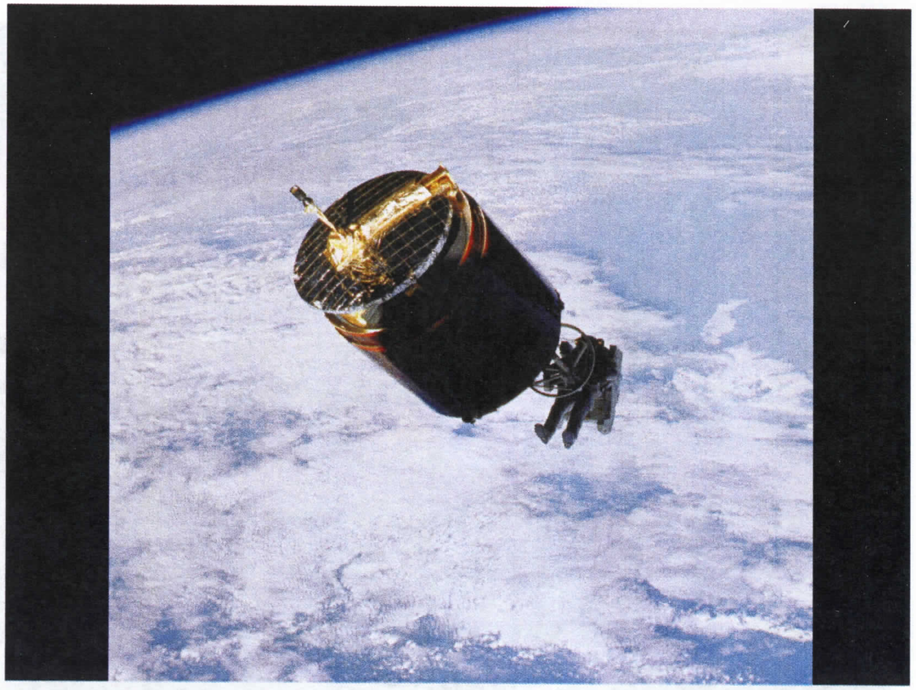
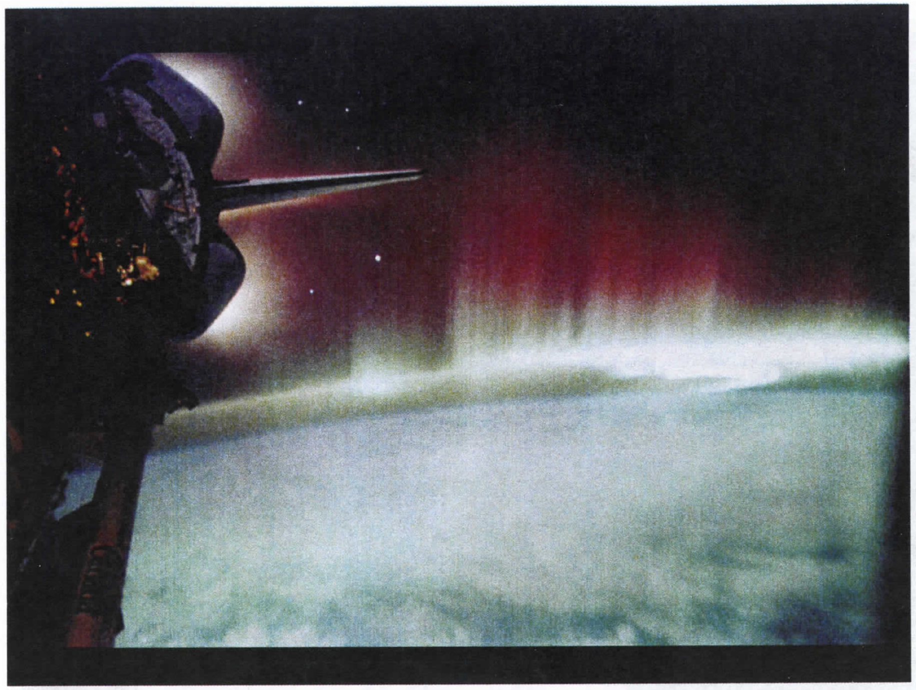
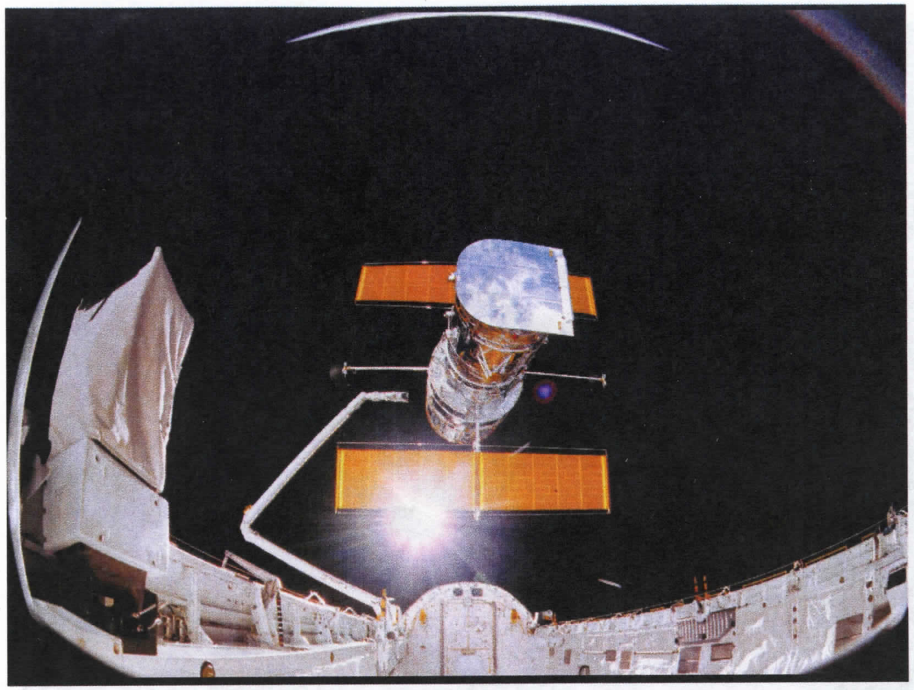

30 YEARS
COLUMBIA CHALLENGER ENDEAVOUR ATLANTIS


April 12 1981
The Launch of STS-1
Exactly 20 years after the flight of Yuri Gagarin

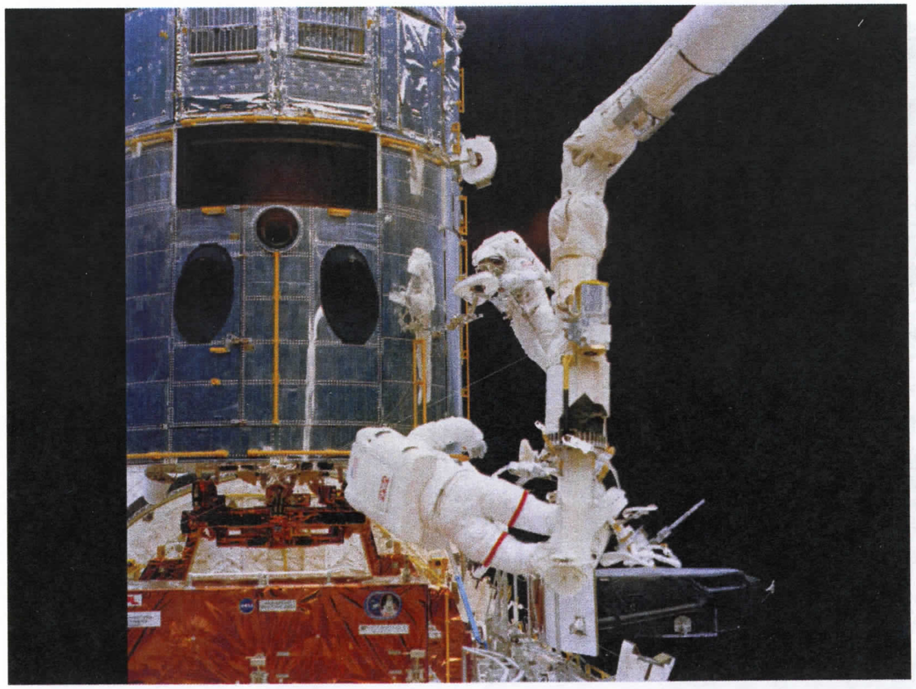

USA

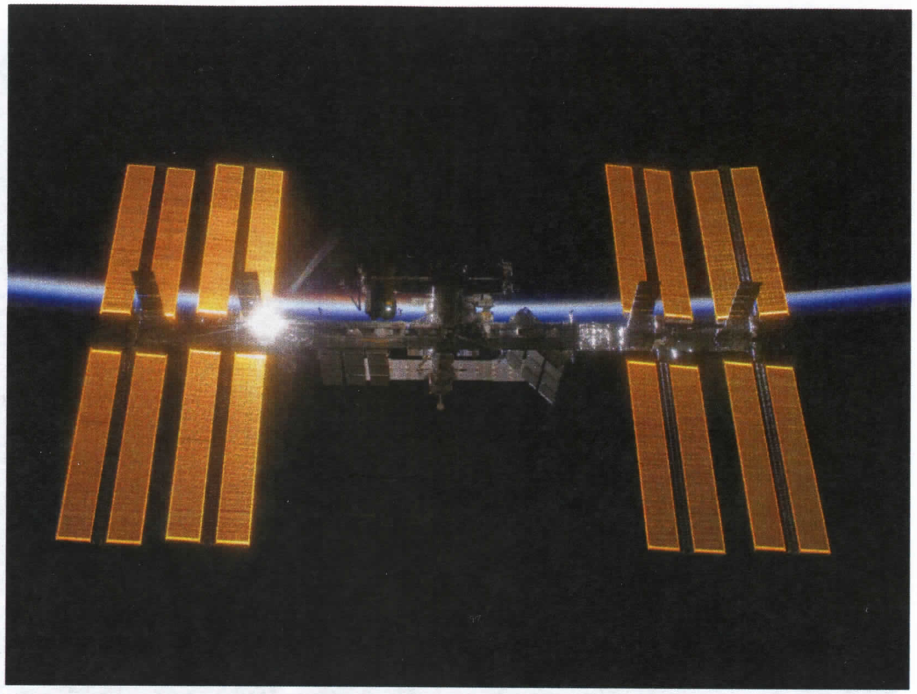


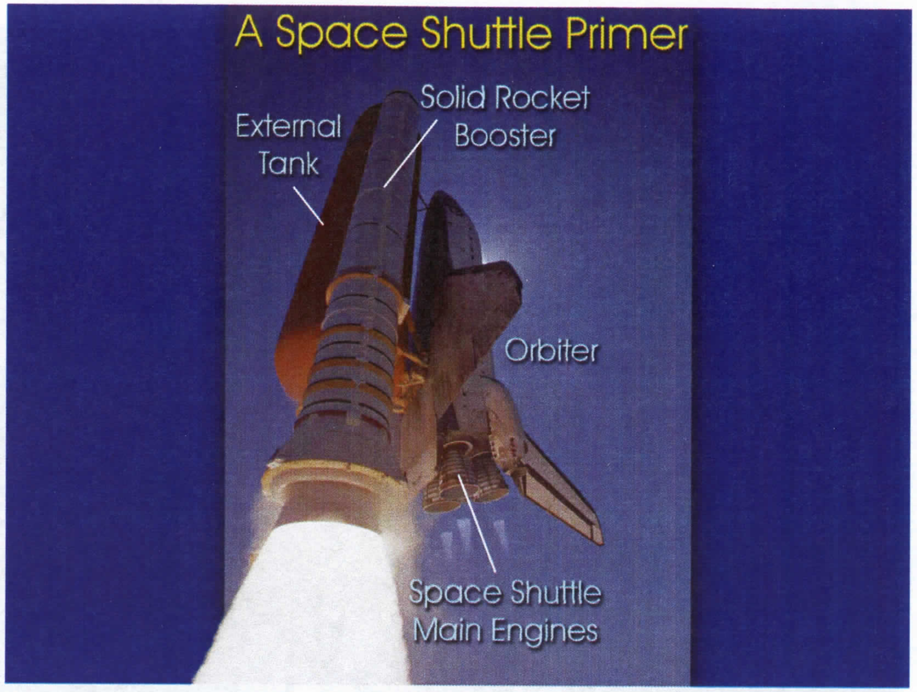


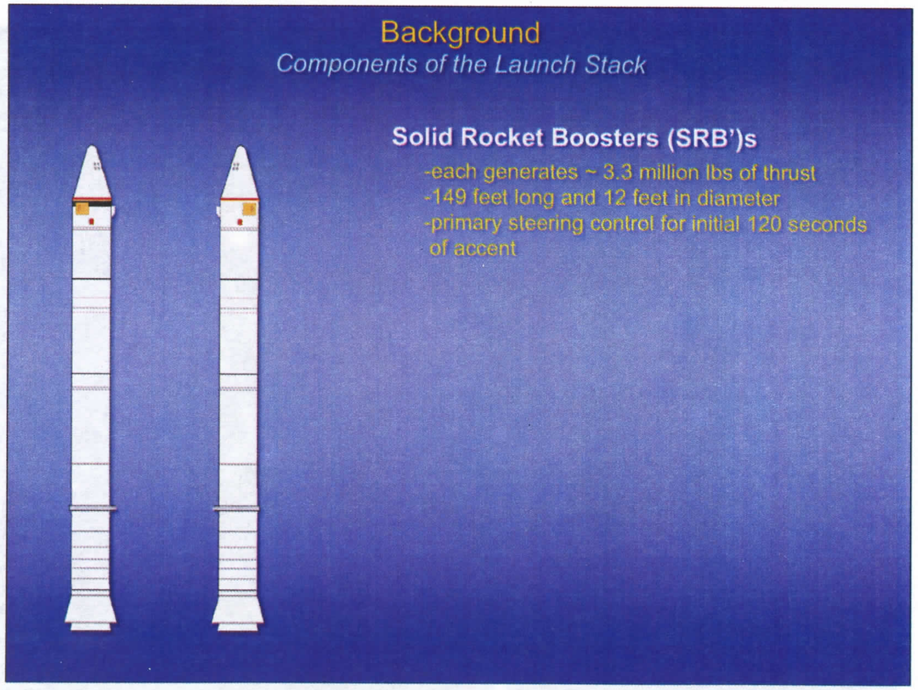


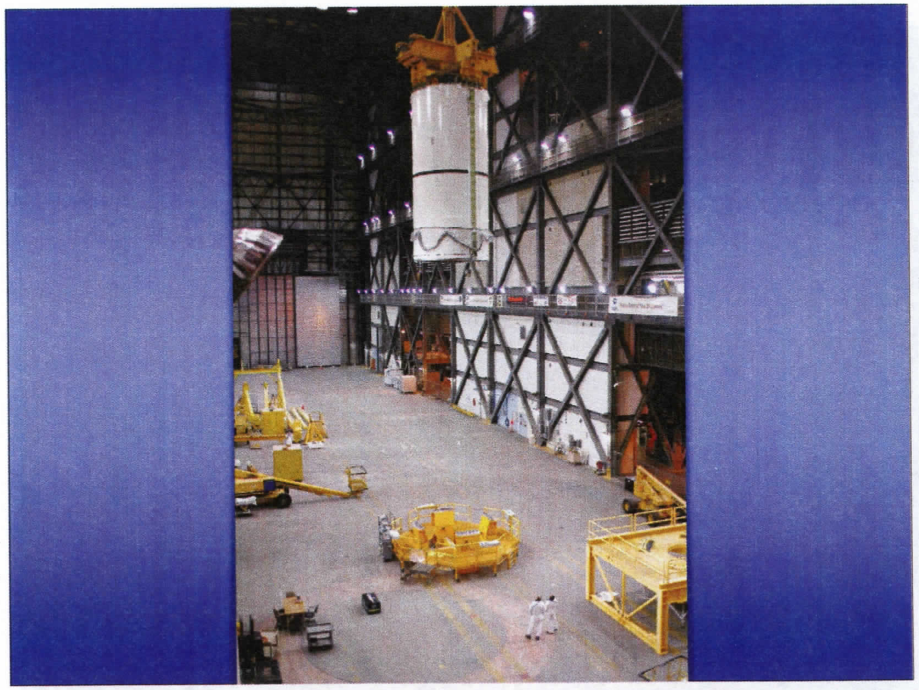

The Cat's Eye Nebula — NGC 6543
HUBBLESITE.org

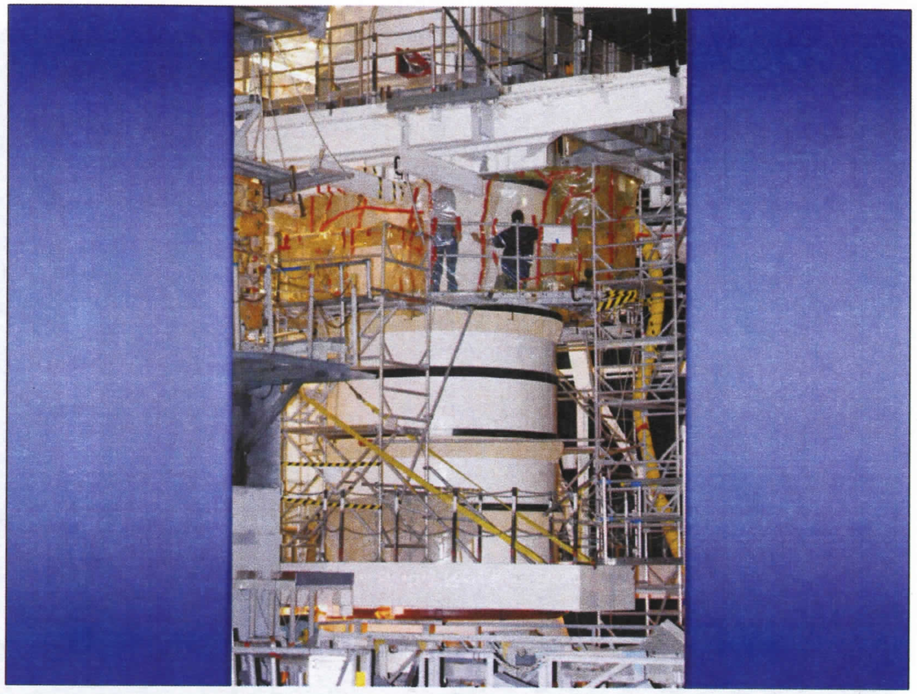





A Space Shuttle Primer
External Tank
Solid Rocket Booster
Orbiter
Space Shuttle Main Engines


Background
Components of the Launch Stack
Solid Rocket Boosters (SRB')s
-each generates ~ 3.3 million lbs of thrust
-149 feet long and 12 feet in diameter
-primary steering control for initial 120 seconds of accent



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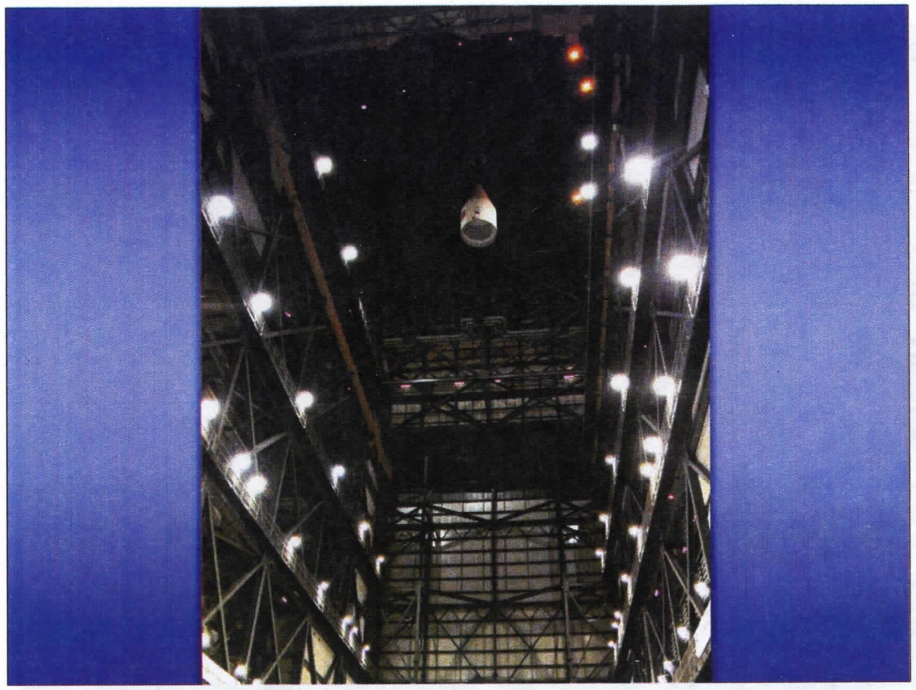
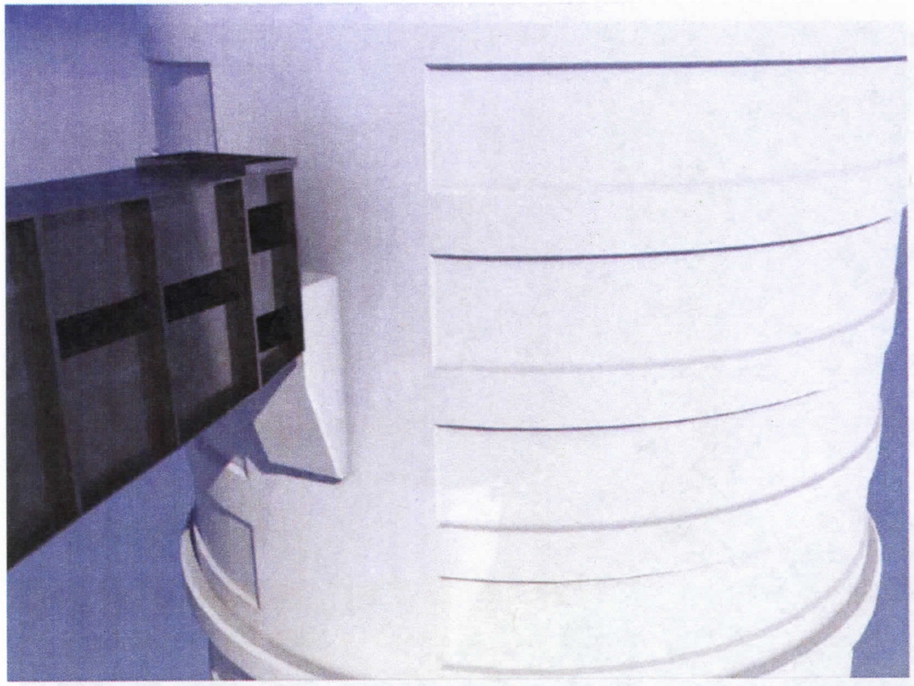
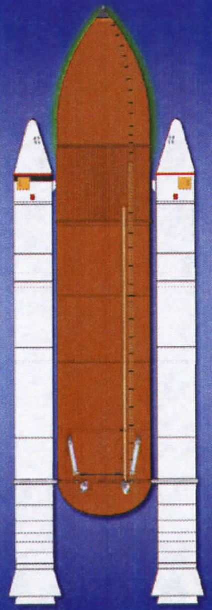




Background

Components of the Launch Stack



Solid Rocket Boosters (SRB's)

-each generates ~ 3.3 million lbs of thrust
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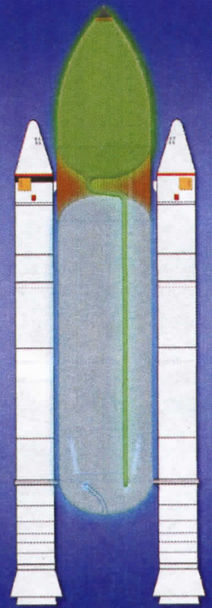
-primary steering control for initial 120 seconds of ascent

External Fuel Tank

-154 feet long and 28.6 feet in diameter
-1.6 million lbs of liquid propellants
-Oxygen Tank: 143,351 Gallons (1.38 million pounds)

Background

Components of the Launch Stack



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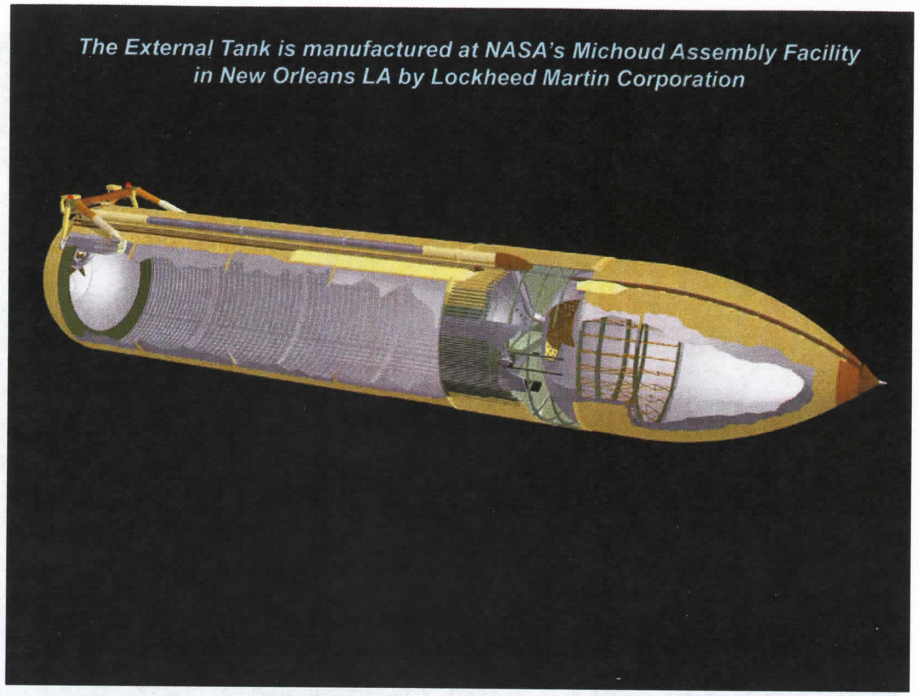
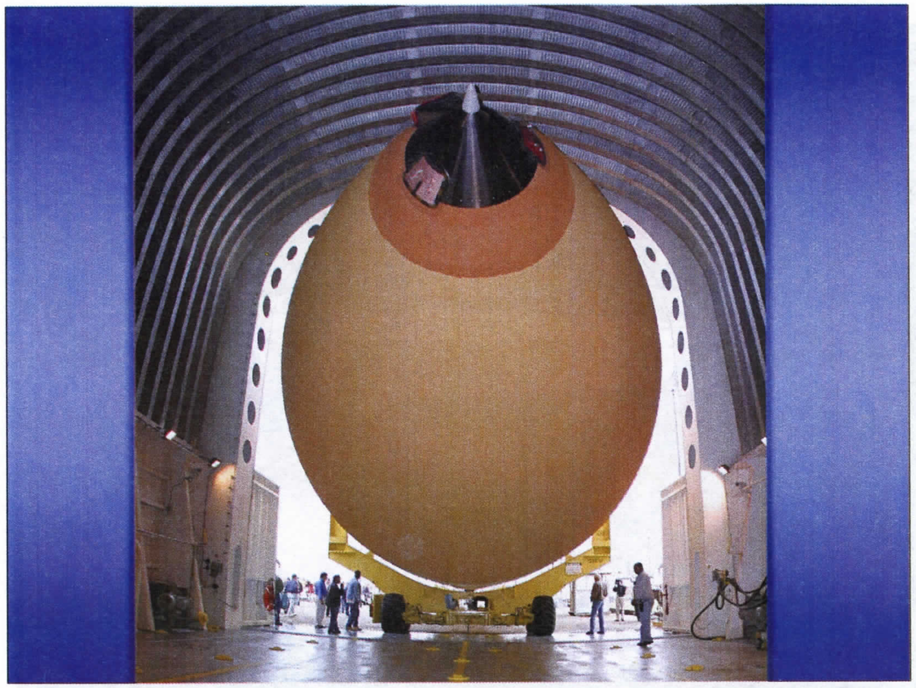
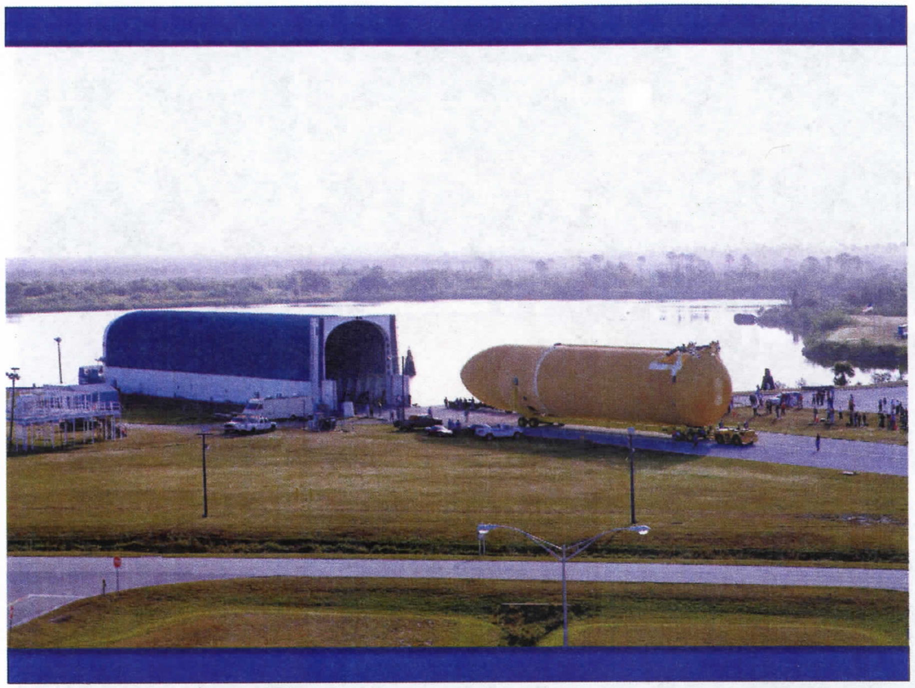
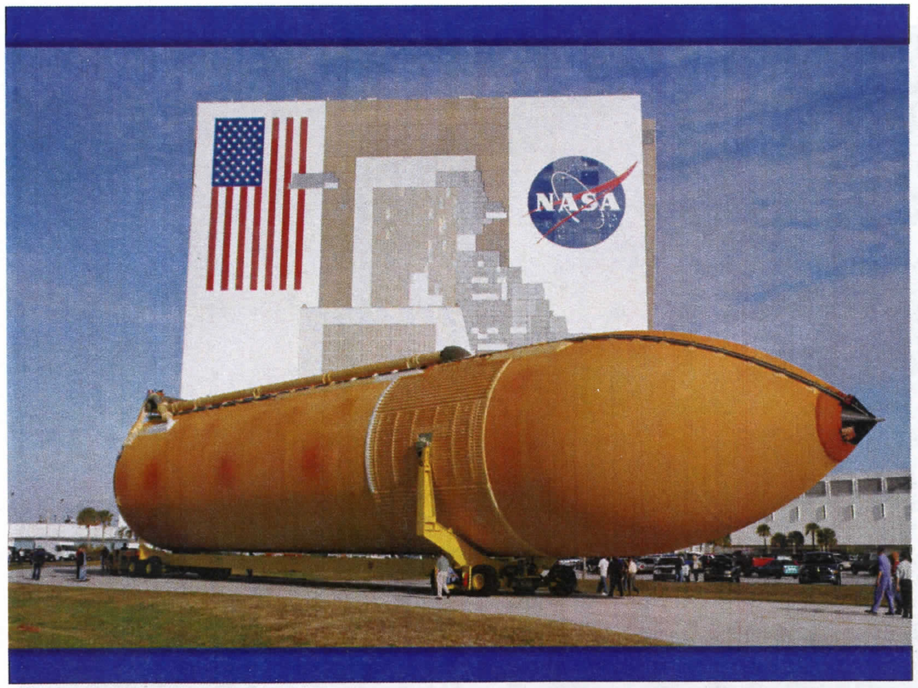
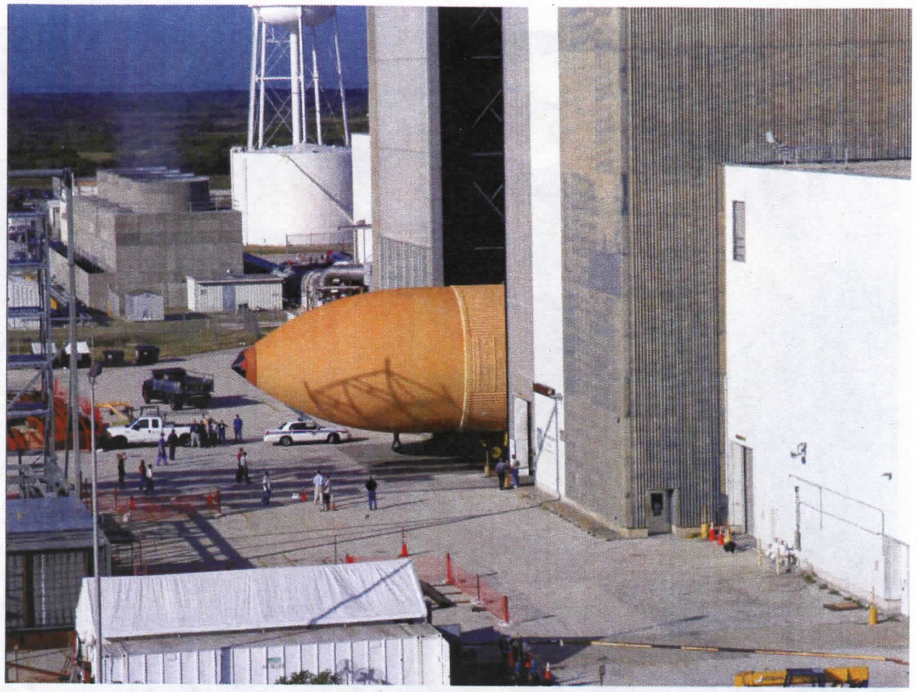
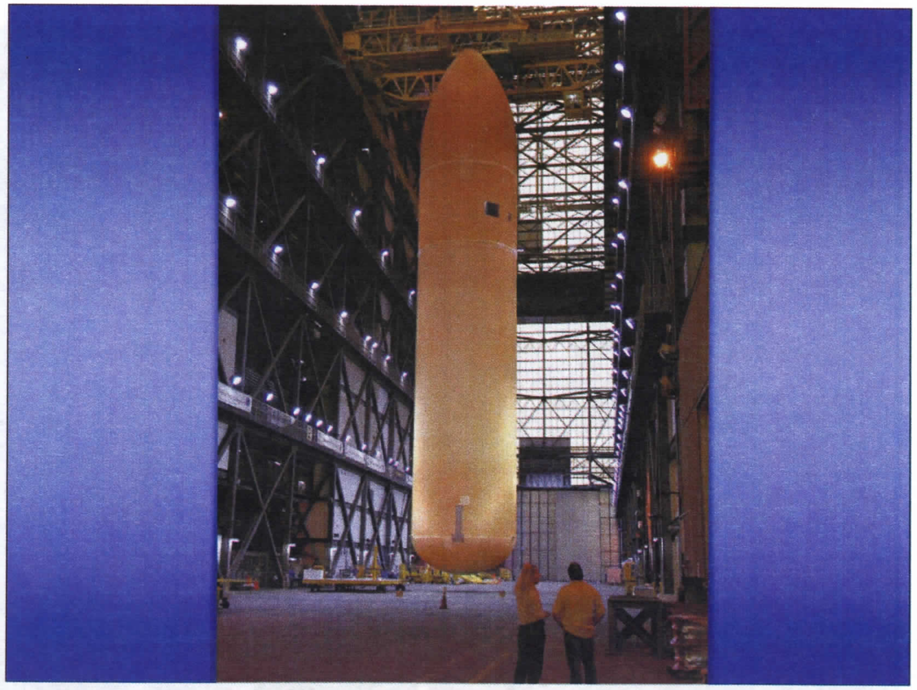

The External Tank is manufactured at NASA's Michoud Assembly Facility
in New Orleans LA by Lockheed Martin Corporation

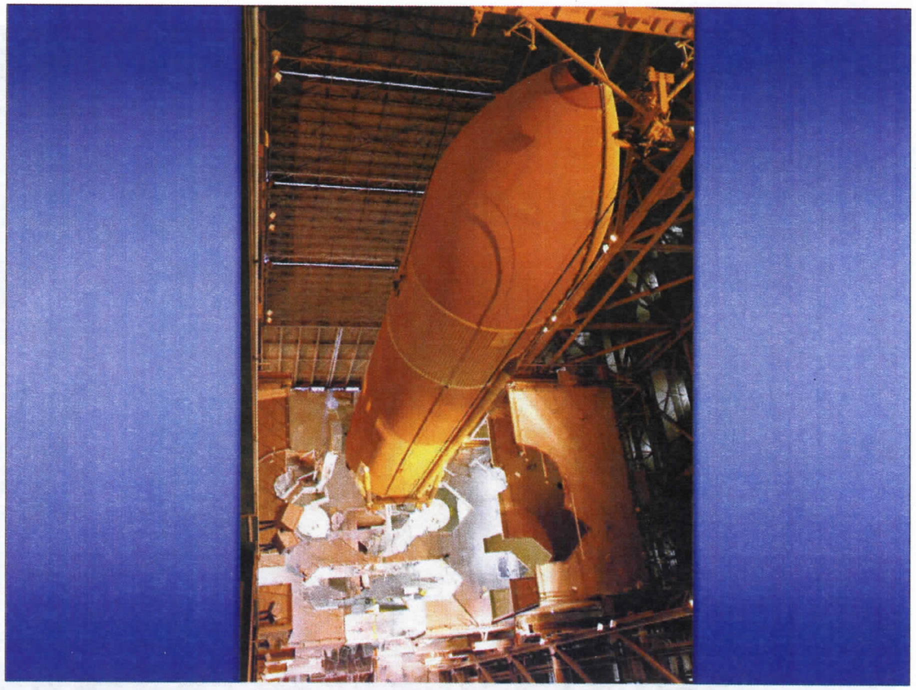


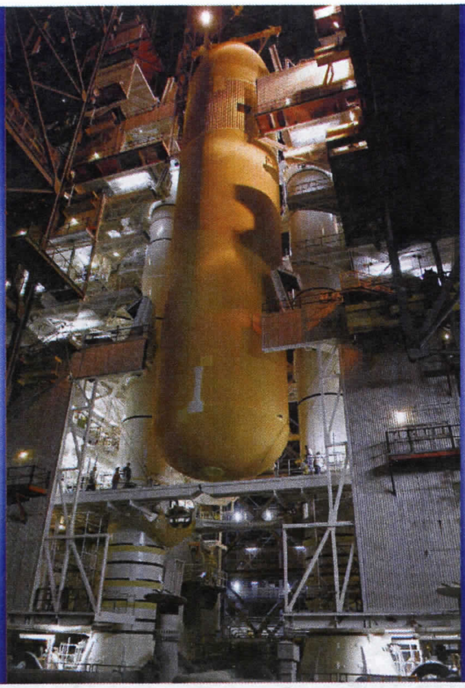


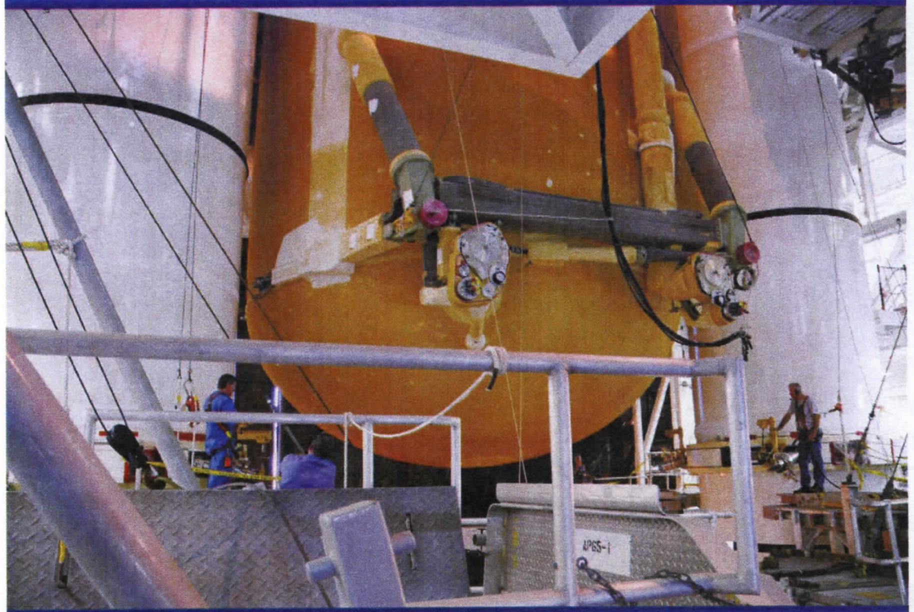

NASA





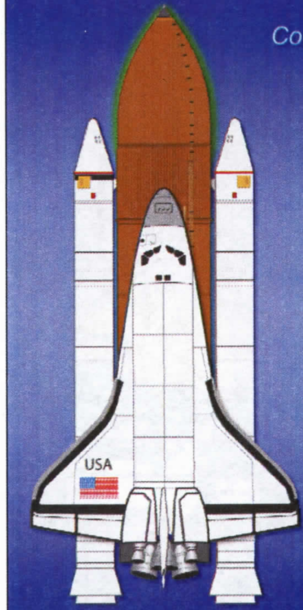






Background

Components of the Launch Stack



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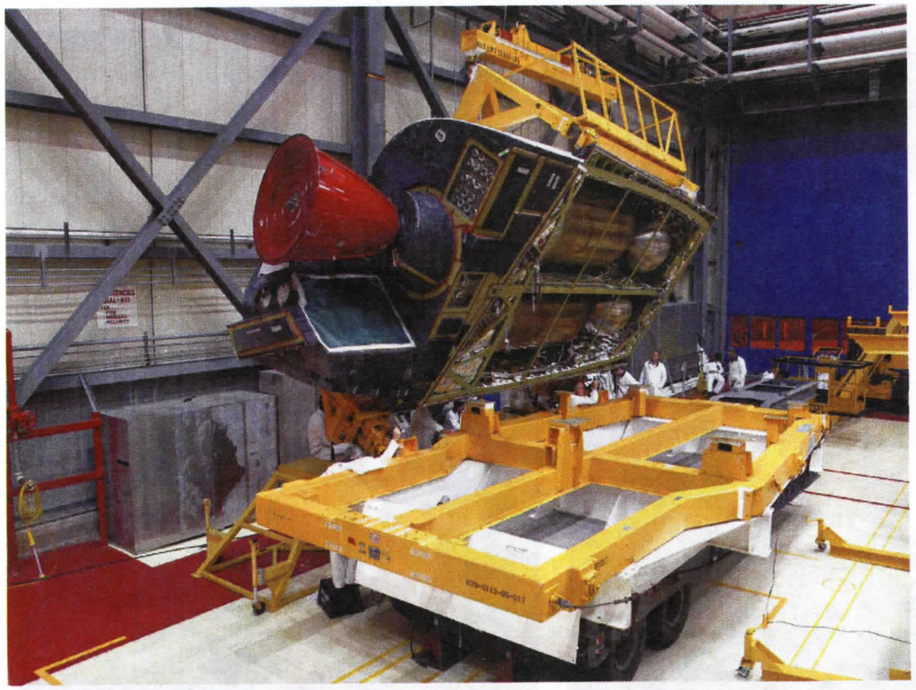
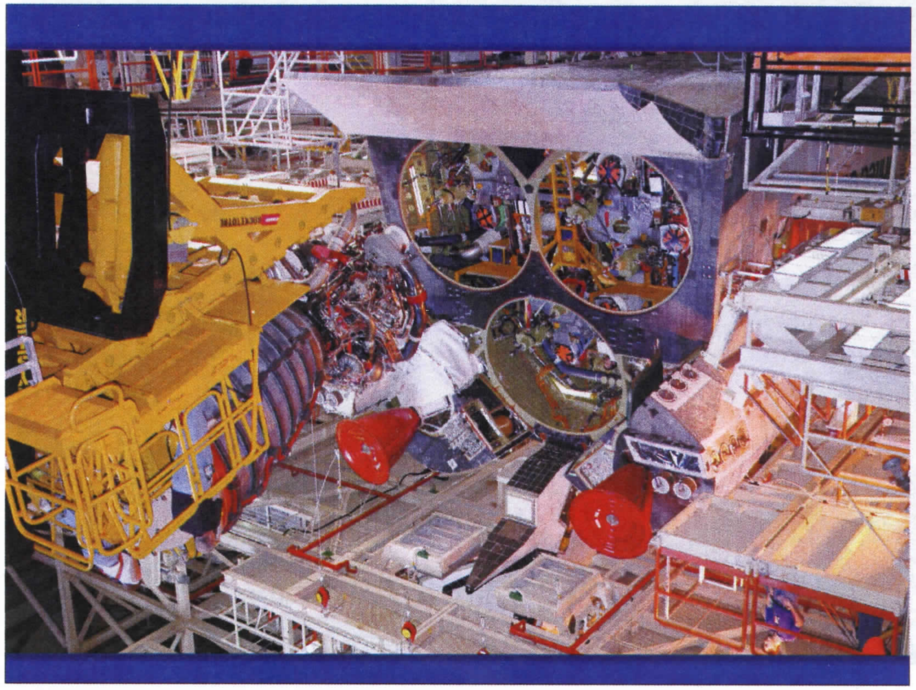
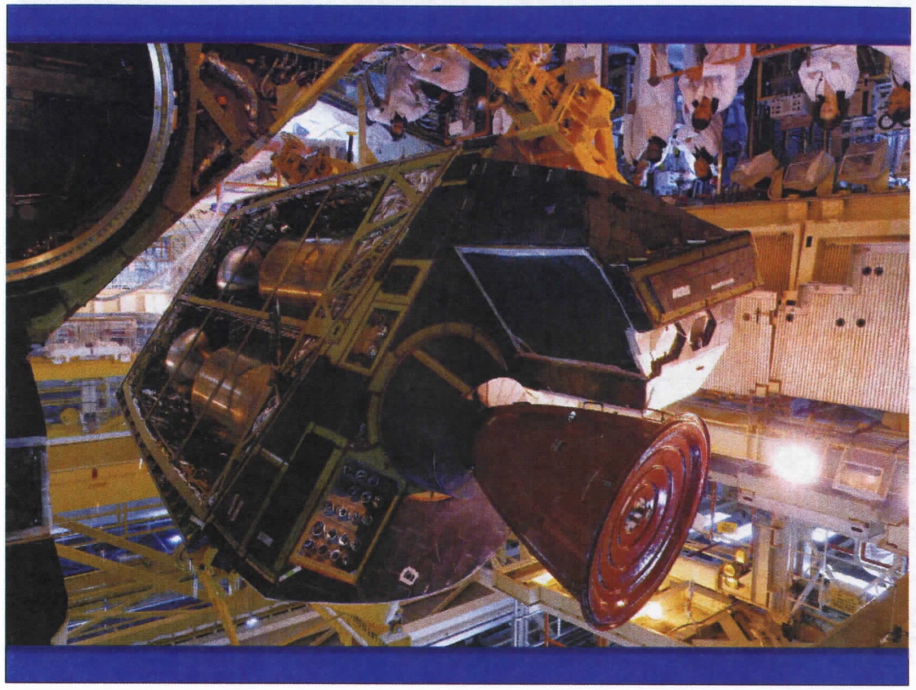
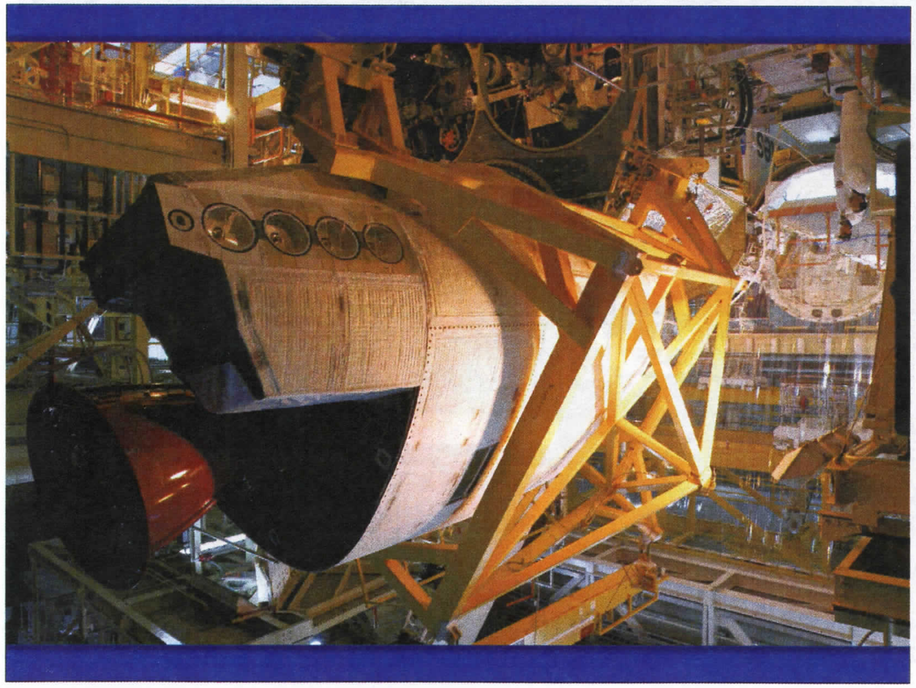
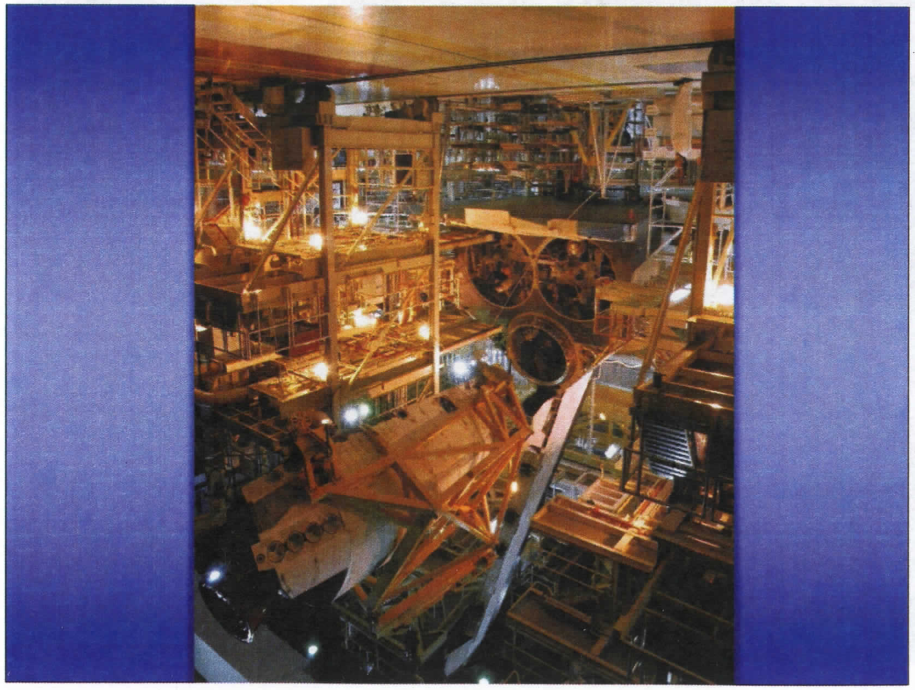
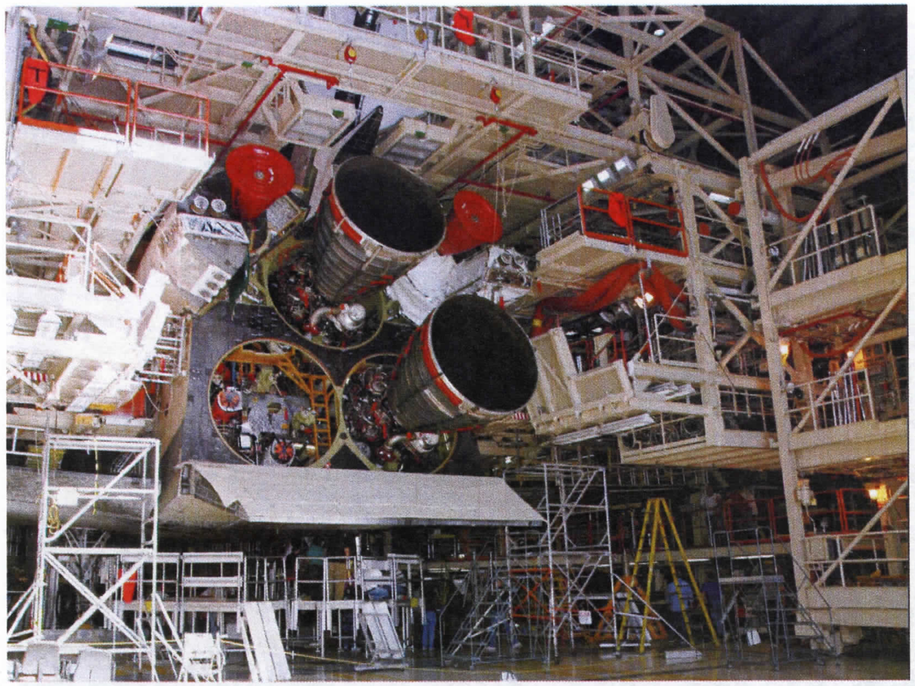
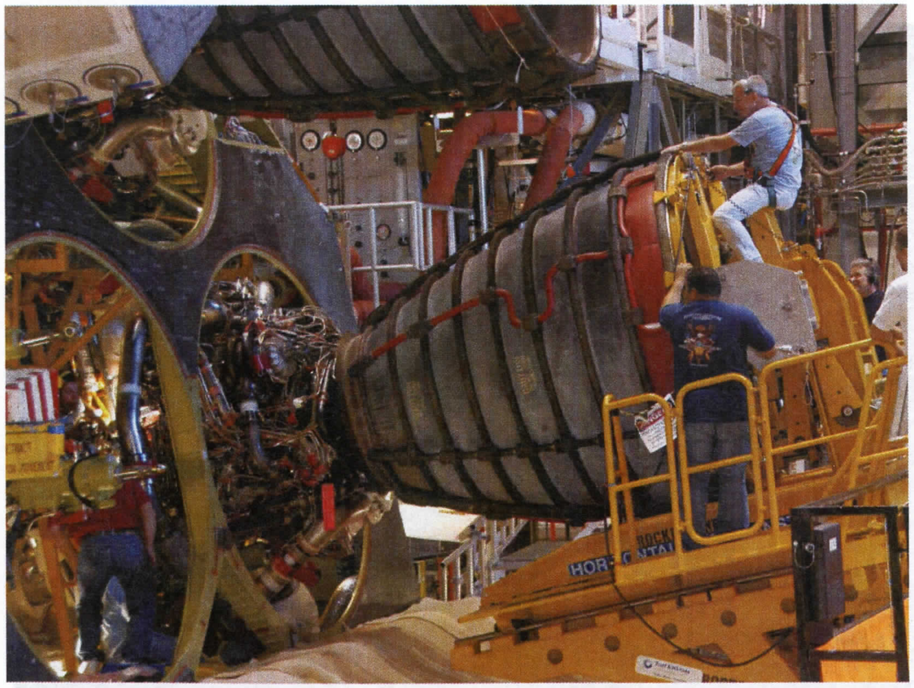
Orbiter

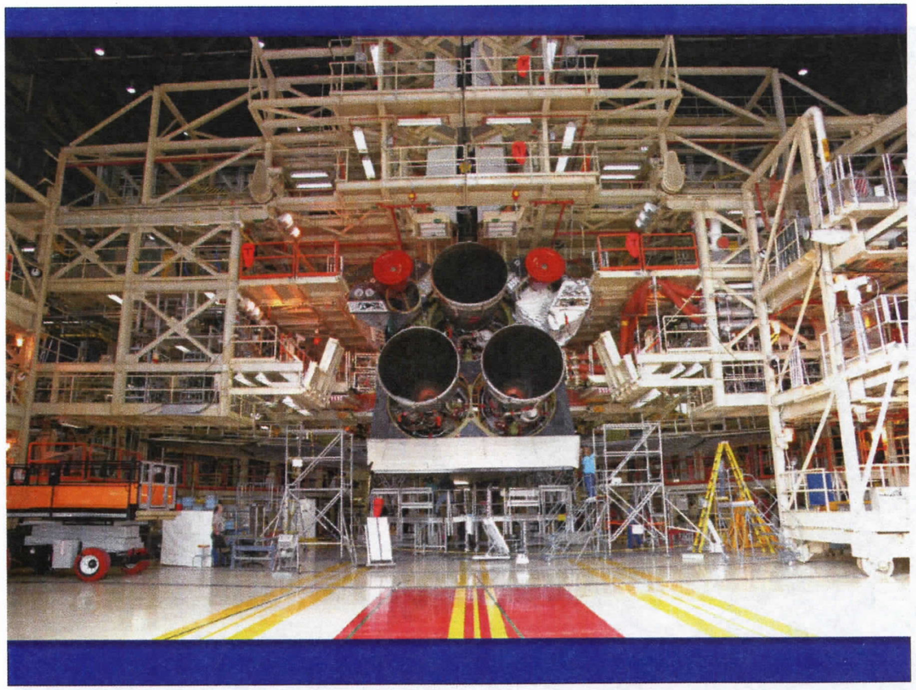
-122 feet long and 57 feet high
-Each of the three main engines generate 375,000 to 470,000 lbs of thrust
-The main engines burn 750 and 280 gallons per second of Hydrogen and Oxygen respectively

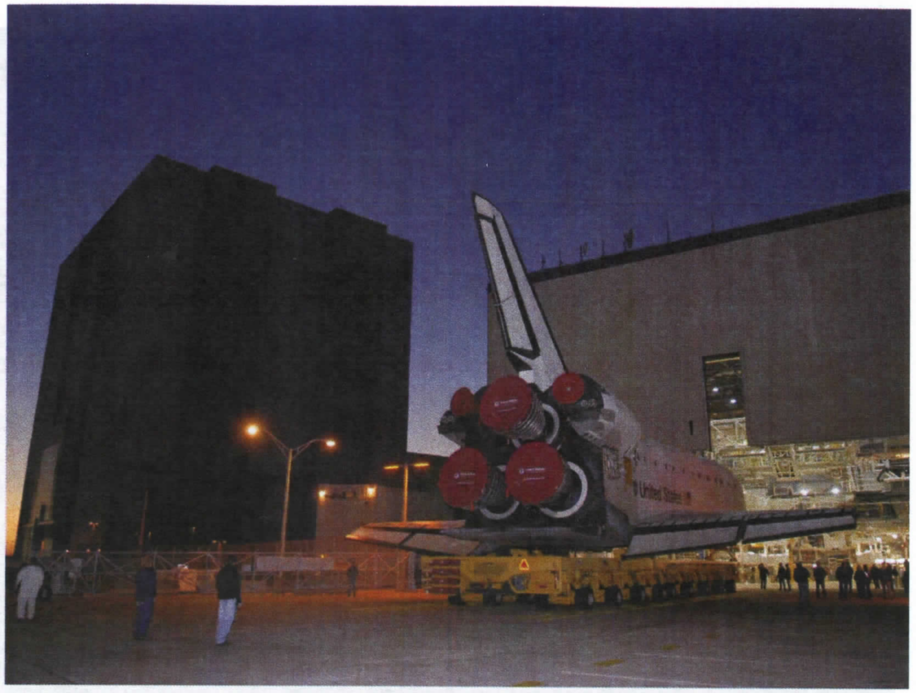


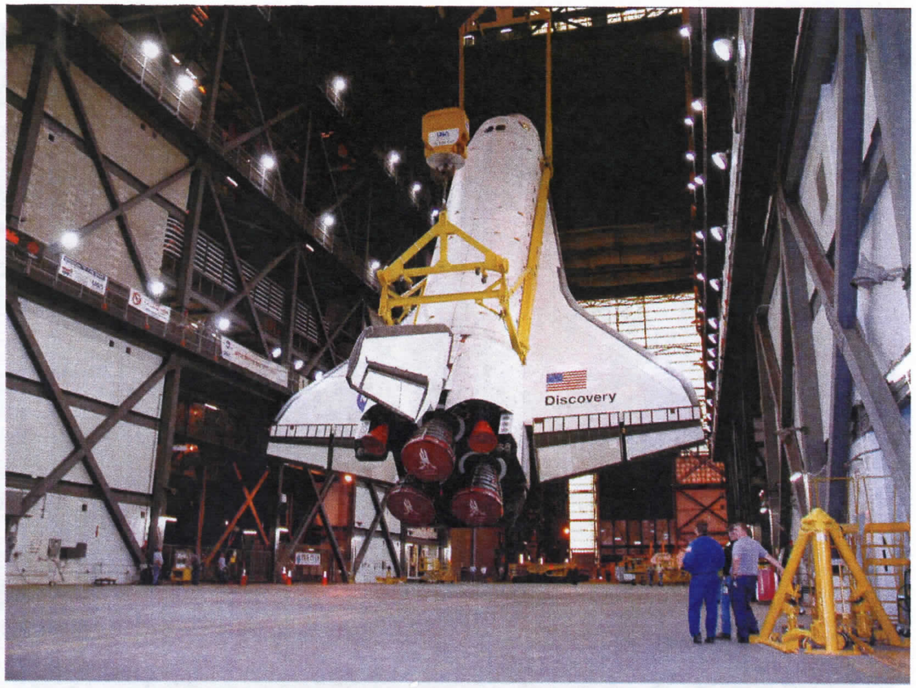




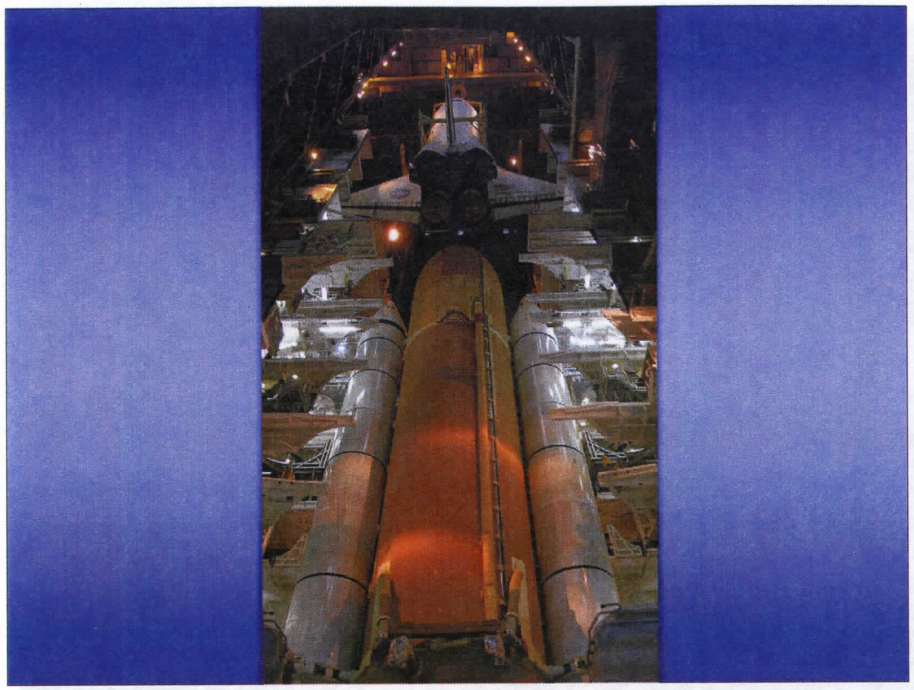


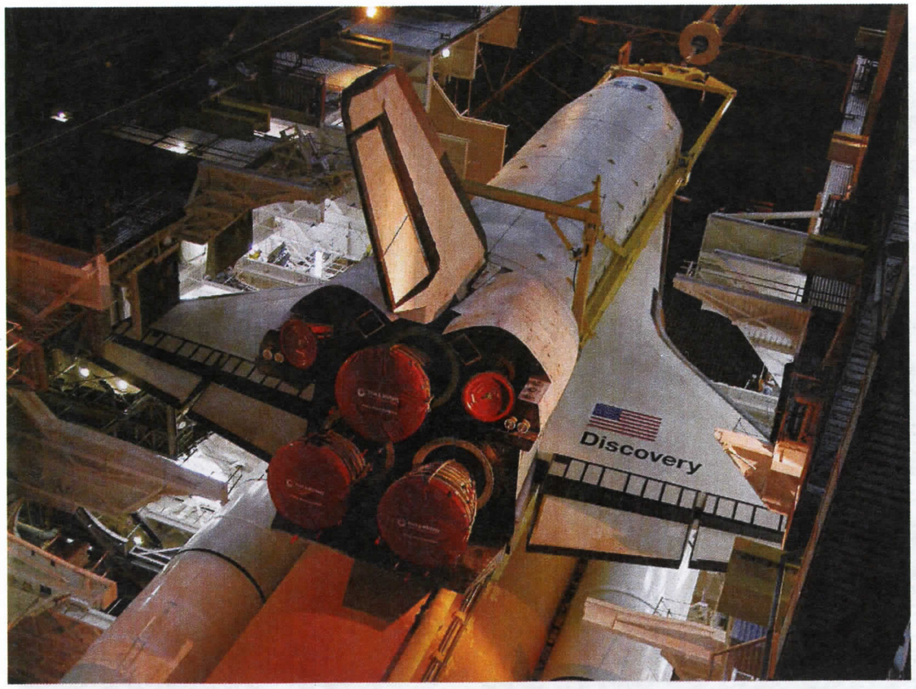


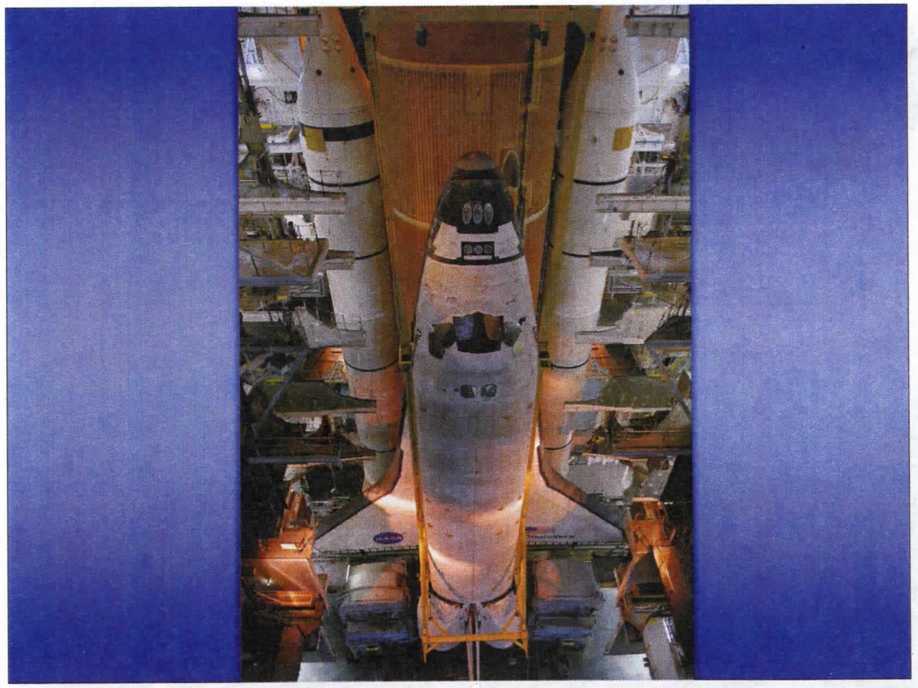

PICK IT UP

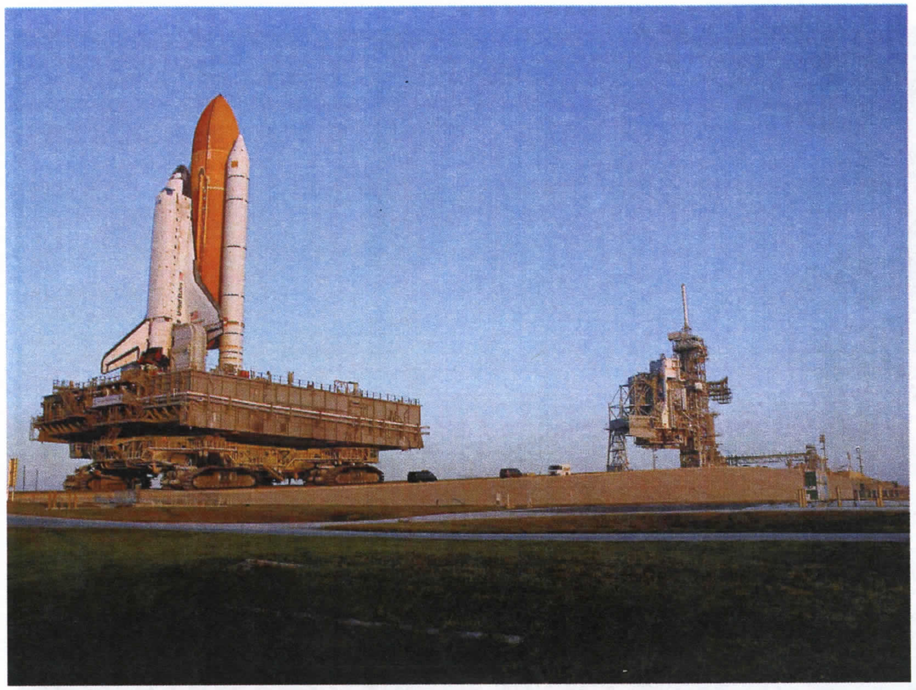

Discovery

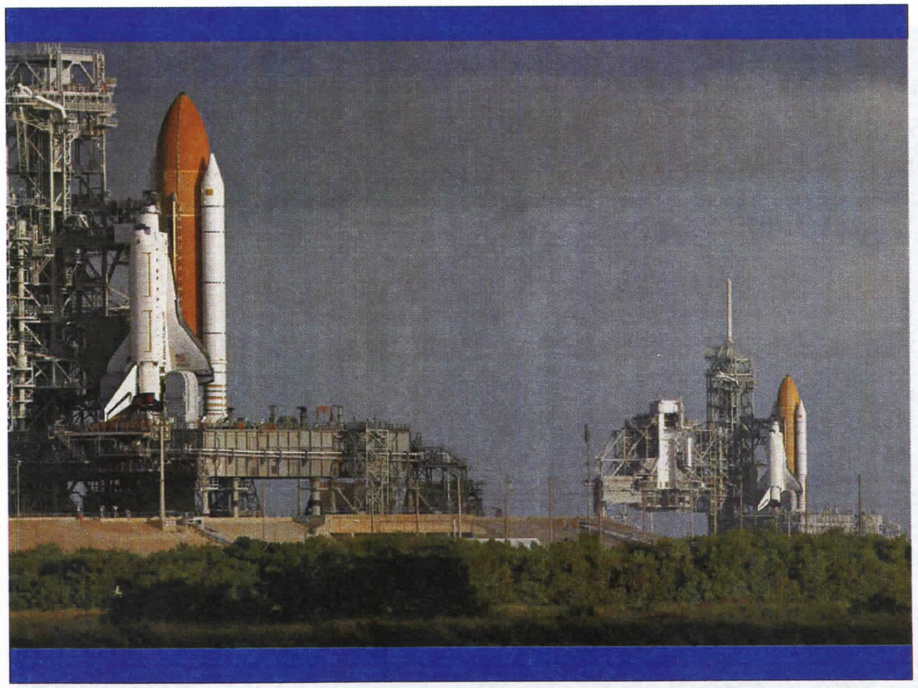

NASA
Discovery

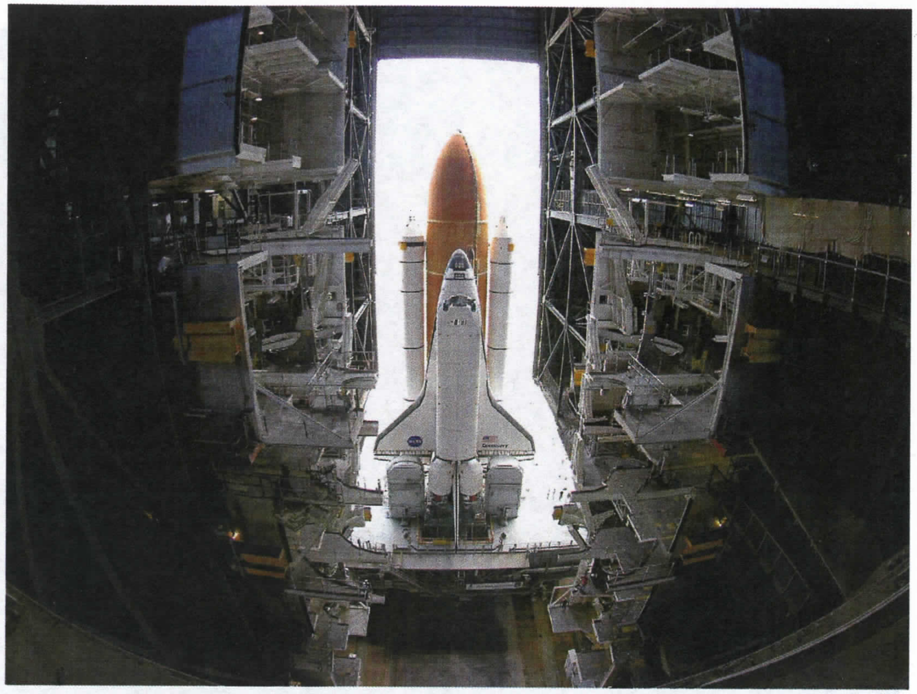



Discovery







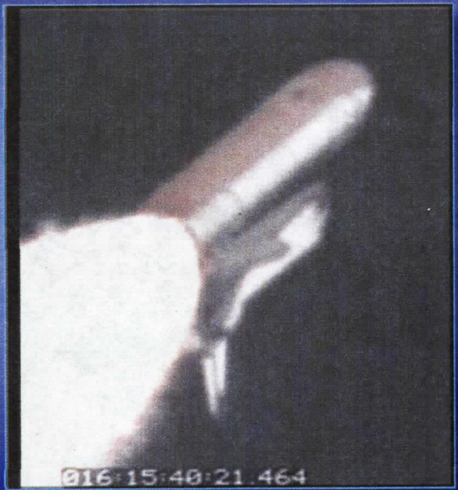


The Columbia Accident

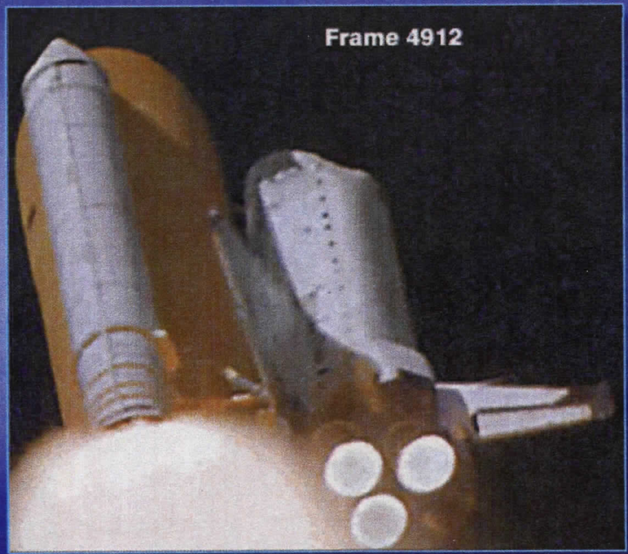
On January 16 2003, Columbia's leading edge was impacted by a piece of foam suspected to have separated from the external tank bipod ramp at 81 seconds into its launch.

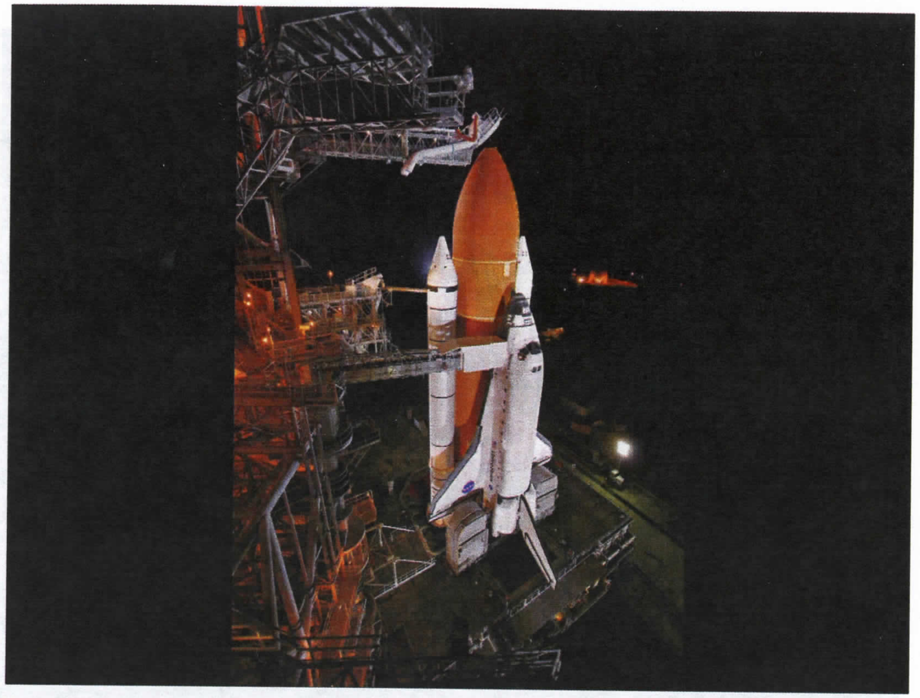
Columbia was traveling at Mach 2.46, at an altitude of 65,860 feet. The foam was calculated to have hit the Orbiter at 700 – 800 feet per second

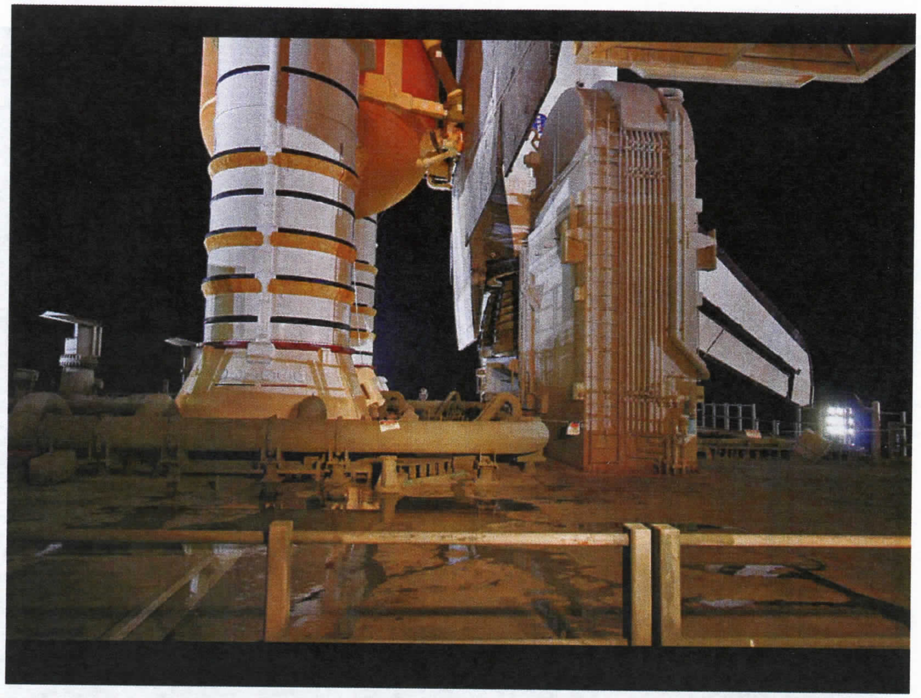
Insulating Foam Separates from Bipod Ramp and Impacts Left Wing of Columbia

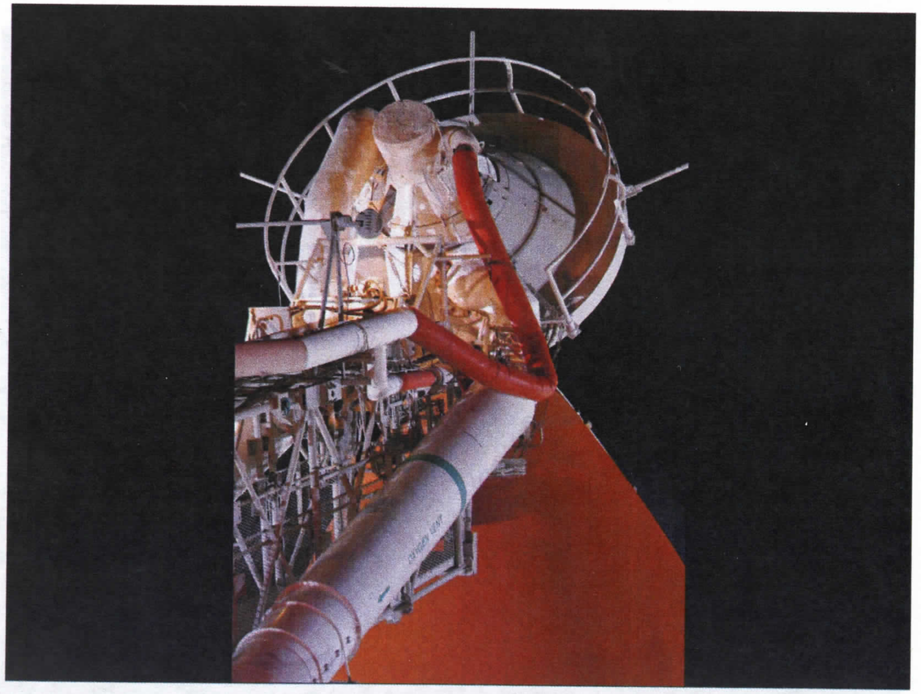


Insulating Foam Separates from Bipod Ramp and Impacts Left Wing of Columbia





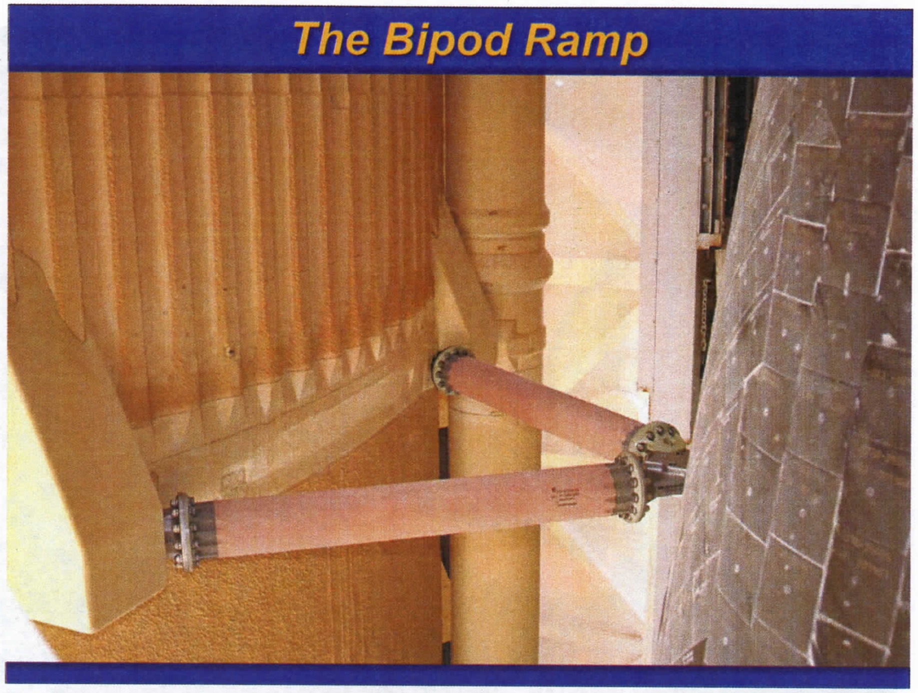


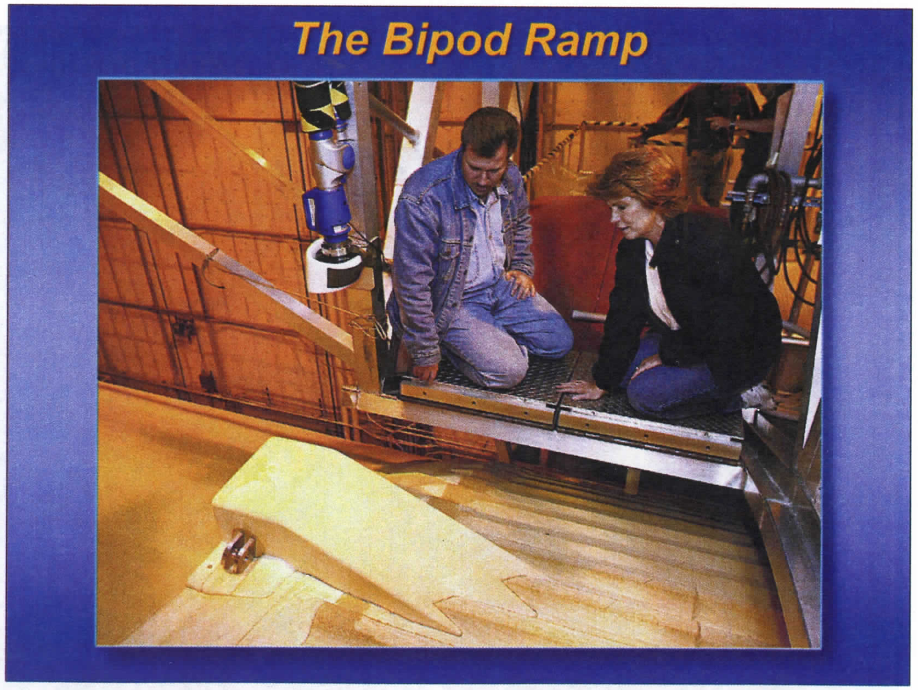


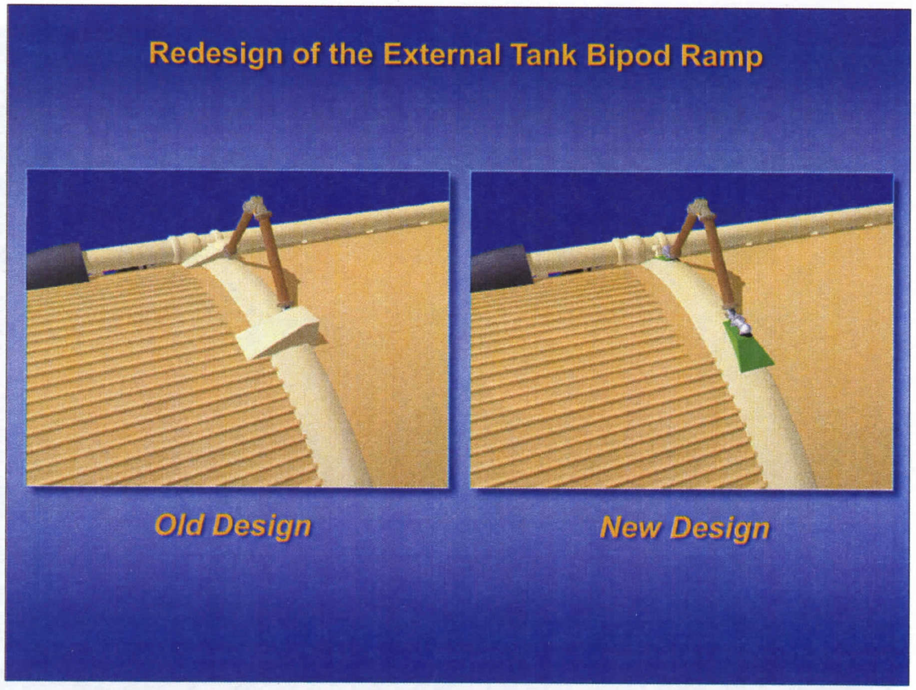
... colossal disasters that do occur, are ultimately failures of design, but the lessons learned from those disasters can do more to advance engineering knowledge than all the successful machines and structures in the world...

Henry Petroski - To Engineer is Human


Bipod
Ramp
Impact
Point

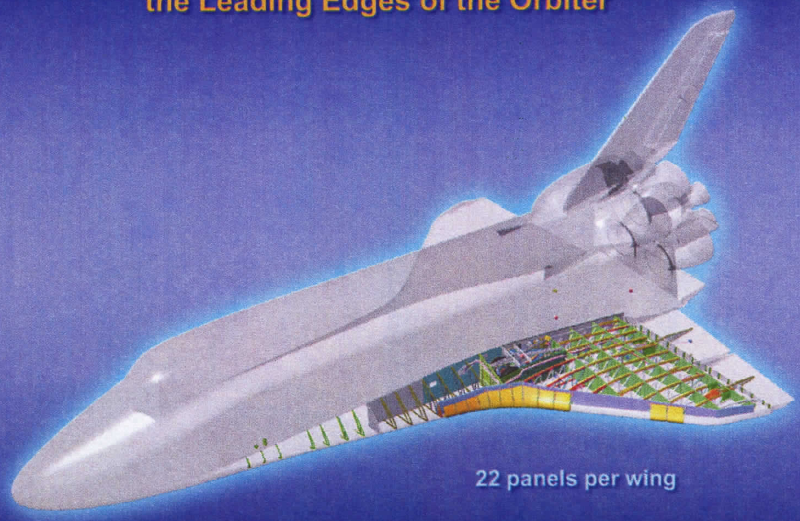

The Bipod Ramp


The Bipod Ramp


Redesign of the External Tank Bipod Ramp
Old Design
New Design

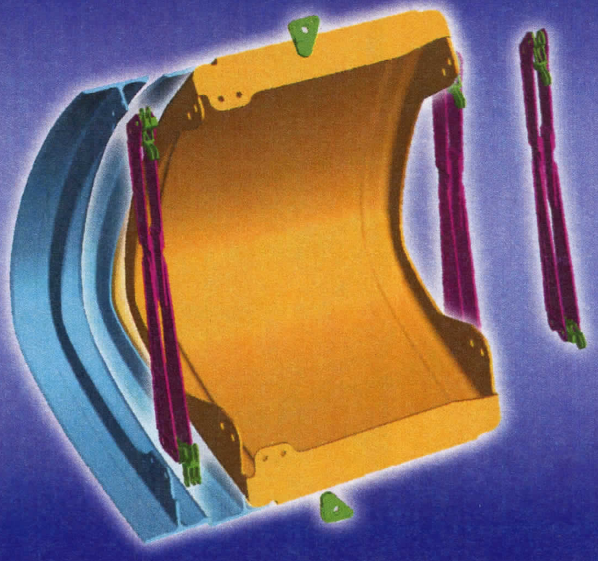
The Orbiter Leading Edges

Reinforced Carbon-Carbon (RCC) Panels Protect the Leading Edges of the Orbiter



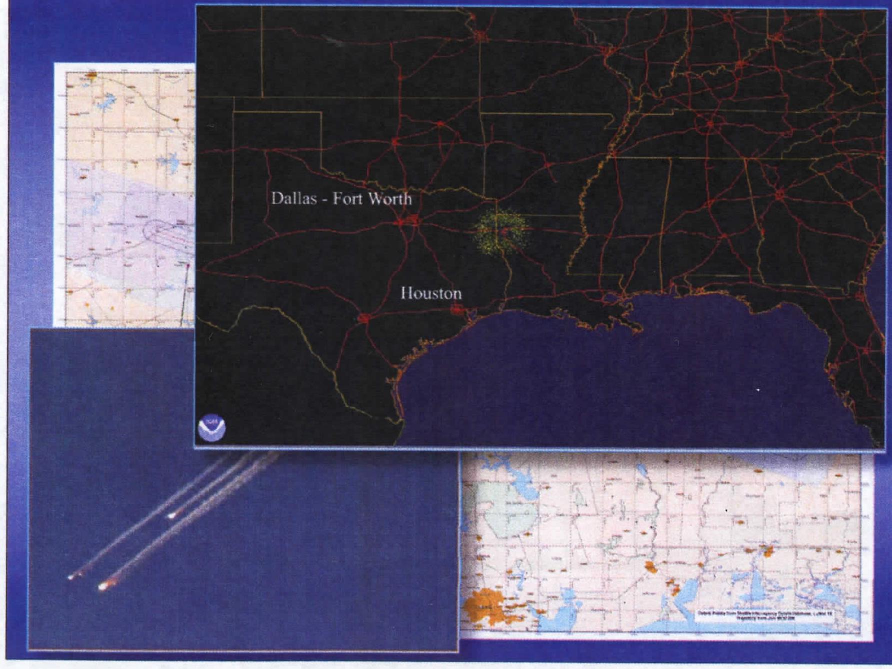
RCC Panels 6, 8 & 9 of Specific Interest

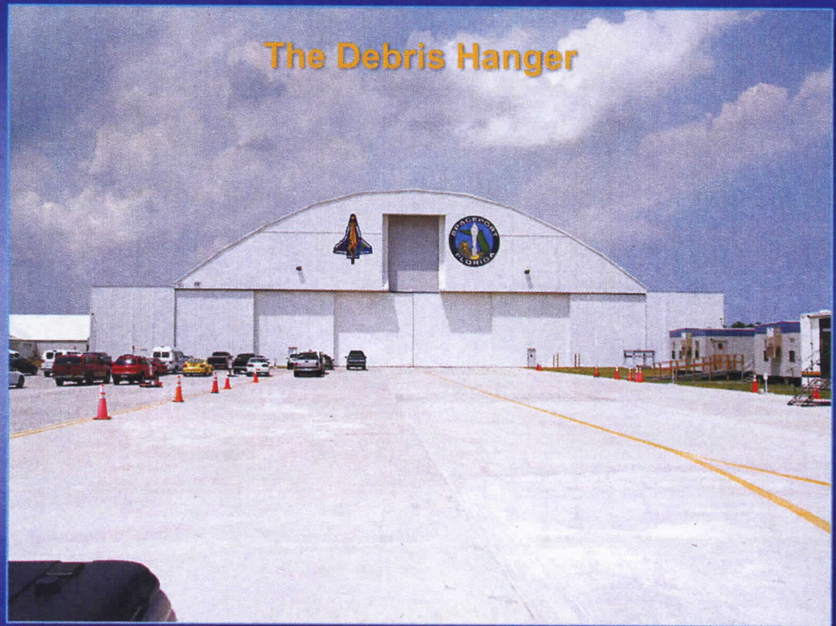
RCC T-Seals Seal the Gap Between Panels



Leading Edge Panel Used for Full Scale Tests

The Reconstruction Effort

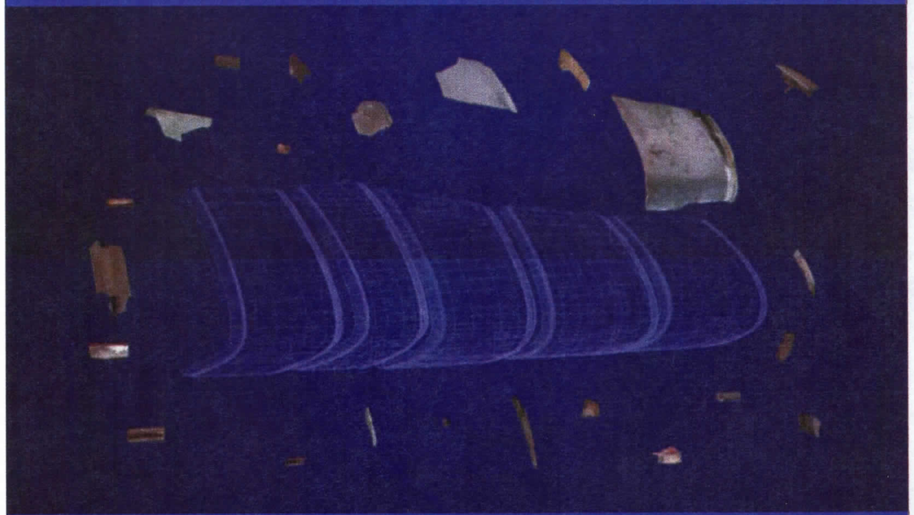


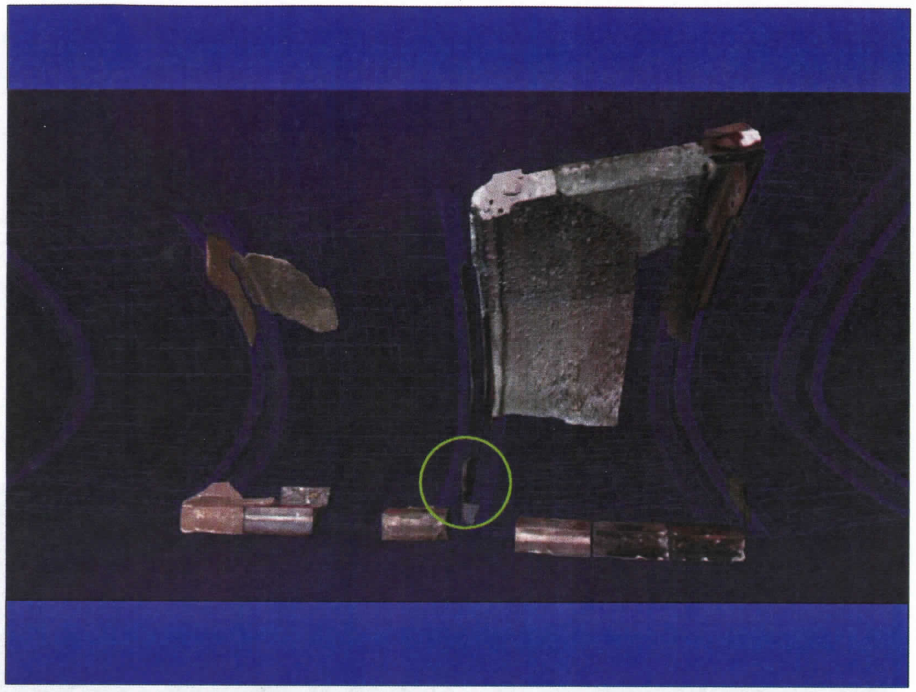


The Debris Hanger

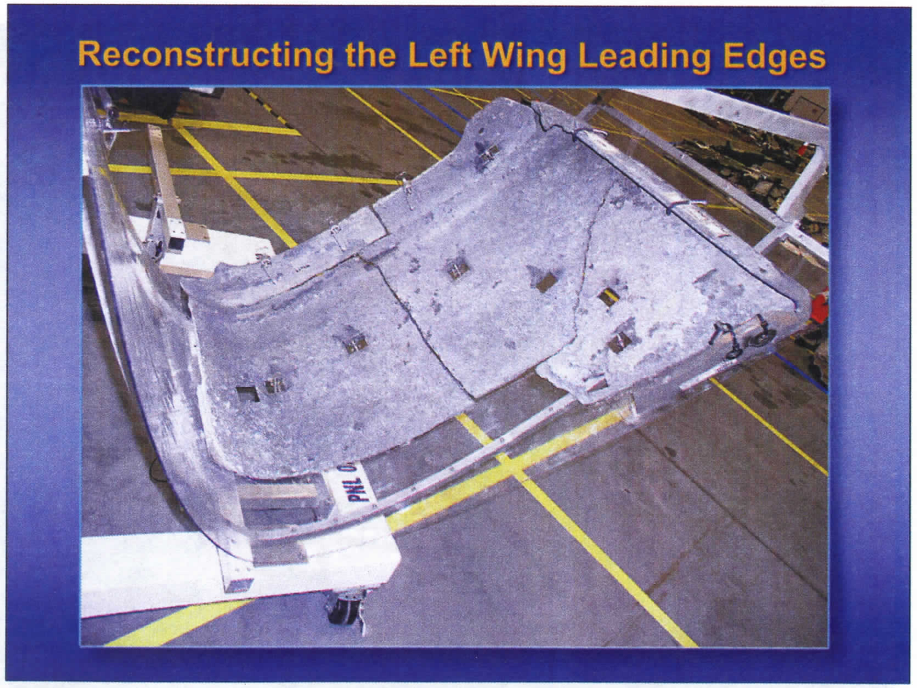
The Debris Hanger

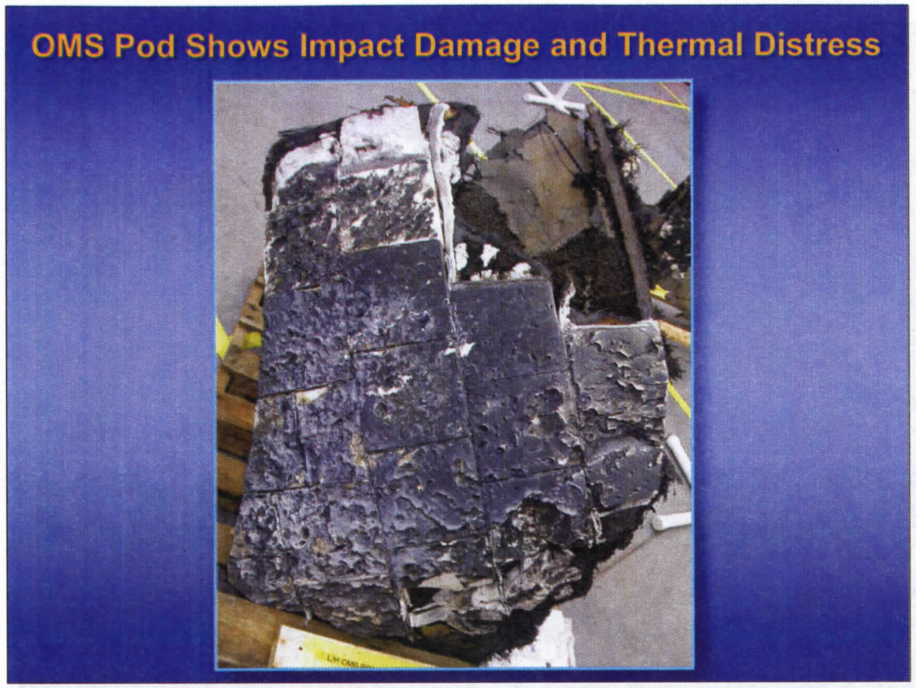
Reconstructing the Left Wing Leading Edges

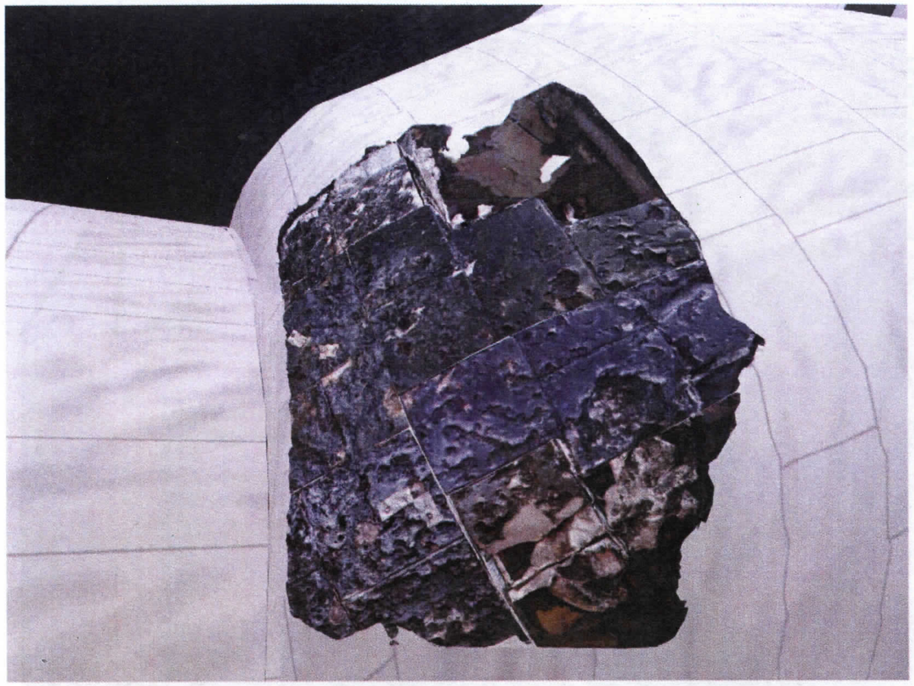


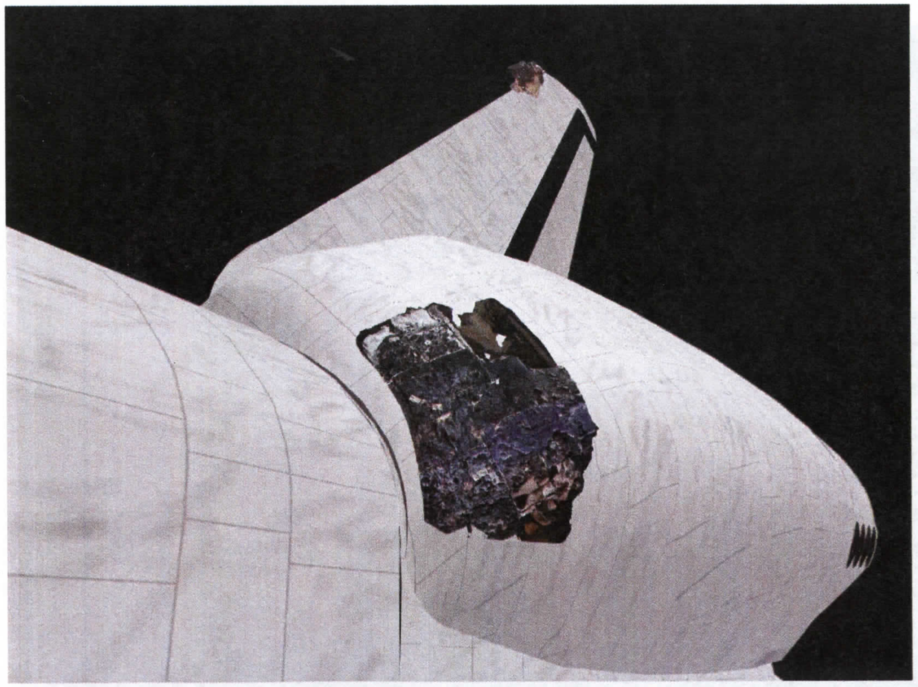


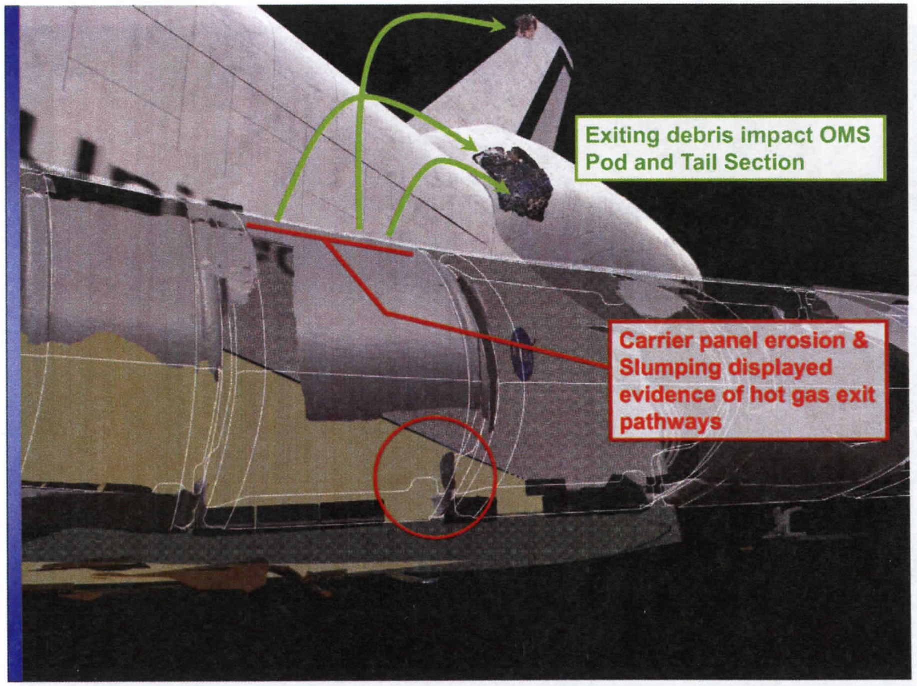

Reconstructing the Left Wing Leading Edges

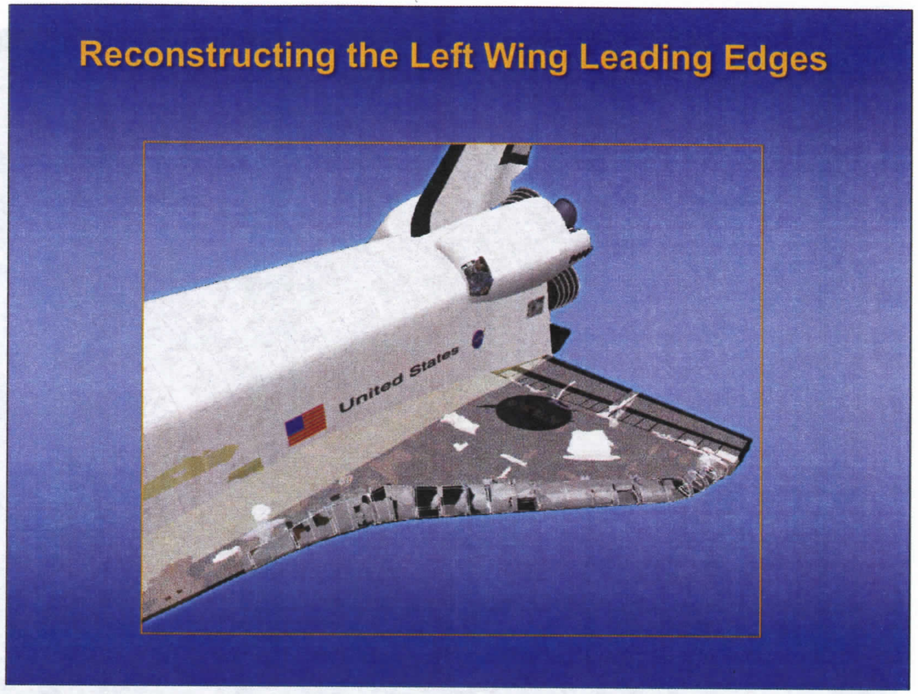

Reconstructing the Left Wing Leading Edges


OMS Pod Shows Impact Damage and Thermal Distress

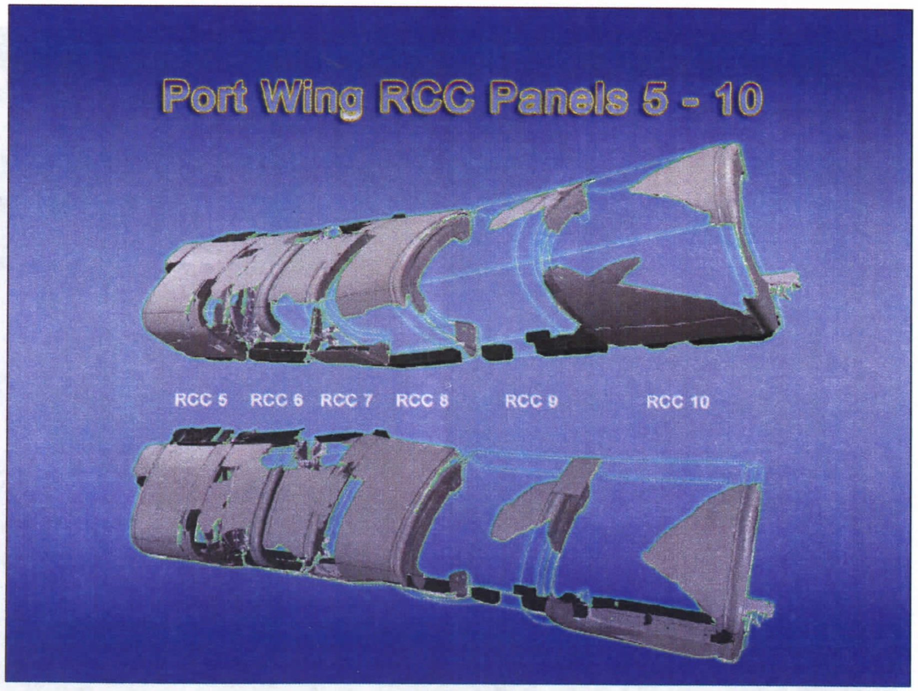


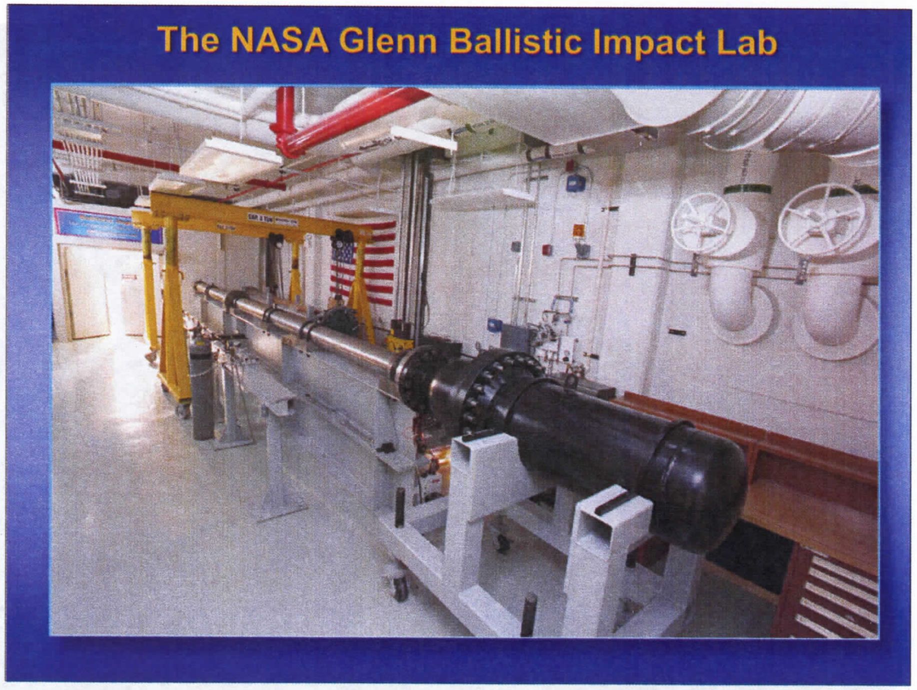



Exiting debris impact OMS Pod and Tail Section
Carrier panel erosion & Slumping displayed evidence of hot gas exit pathways

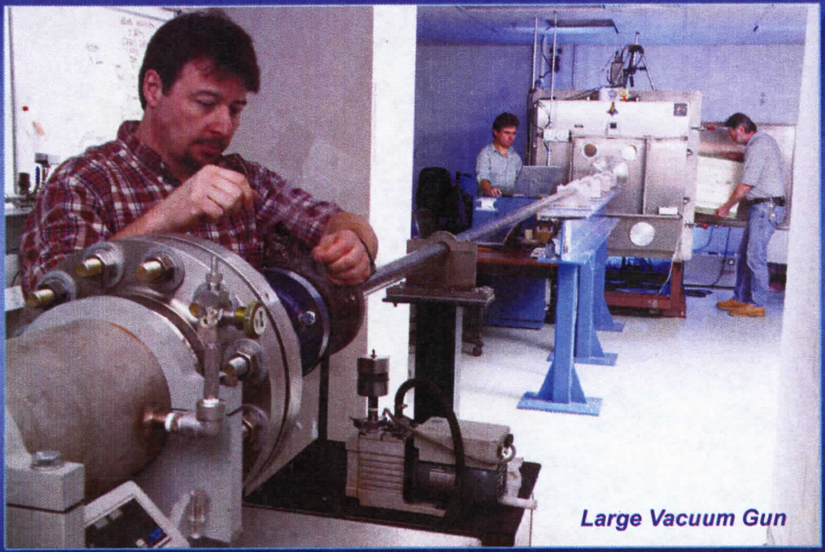

Reconstructing the Left Wing Leading Edges
United States


Reconstructing the Left Wing Leading Edges


Port Wing RCC Panels 5 - 10
RCC 5
RCC 6
RCC 7
RCC 8
RCC 9
RCC 10


The NASA Glenn Ballistic Impact Lab

The NASA Glenn Ballistic Impact Lab



Large Vacuum Gun

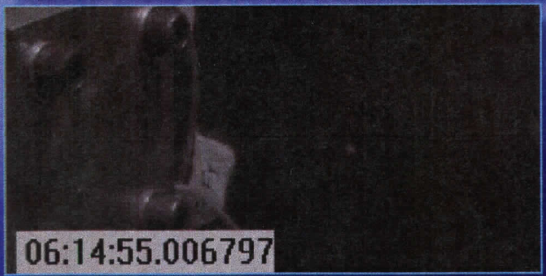
BX-250 External Tank Foam Characterization

Ballistic Research Supporting the Accident Investigation

BX-250 External Tank Foam Characterization

High Speed Video of 90 Degree Impacts

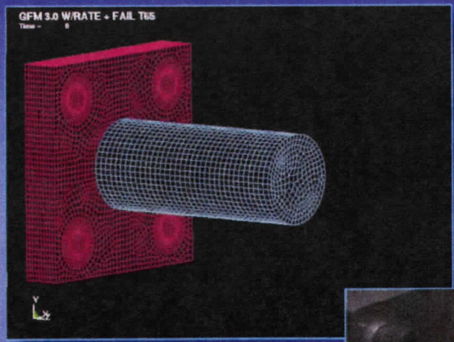
No Vacuum
708 ft/sec



Vacuum
693 ft/sec

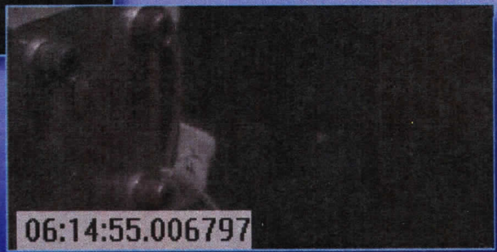
Ballistic Research Supporting the Accident Investigation

Dyna - explicit finite element impact analysis



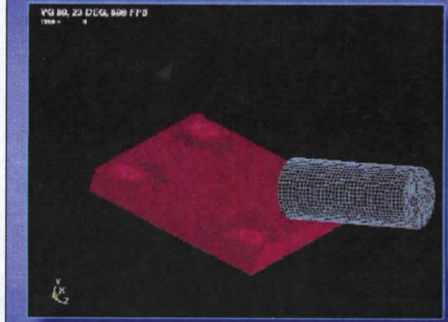
Dyna Predicts 90 Degree Foam Impact on Load Cell

Dyna is an industry standard commercial finite element analysis code typically used to model impact events

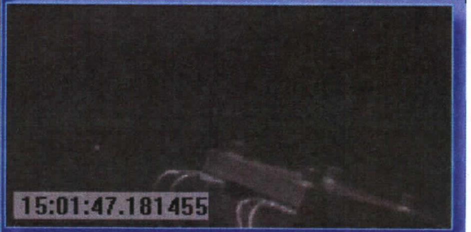


Ballistic Research Supporting the Accident Investigation

Dyna - explicit finite element impact analysis



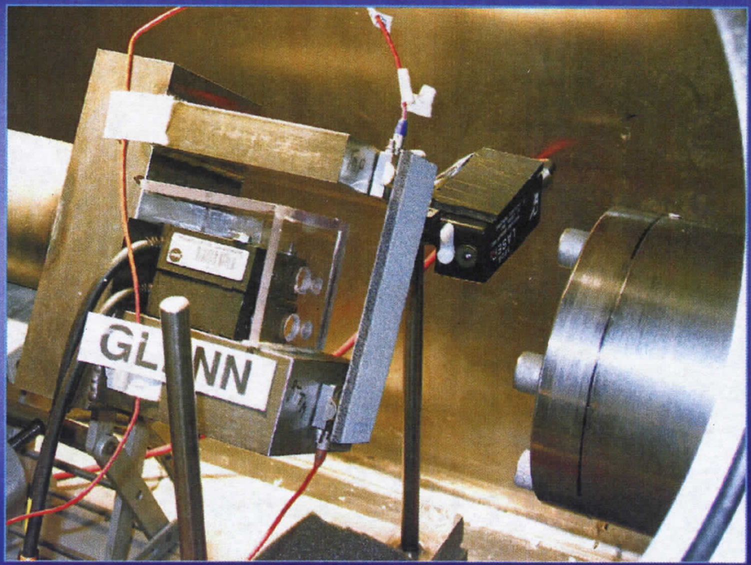
Dyna Predicts 23 Degree Foam Impact on Load Cell



Reinforced Carbon-Carbon Characterization

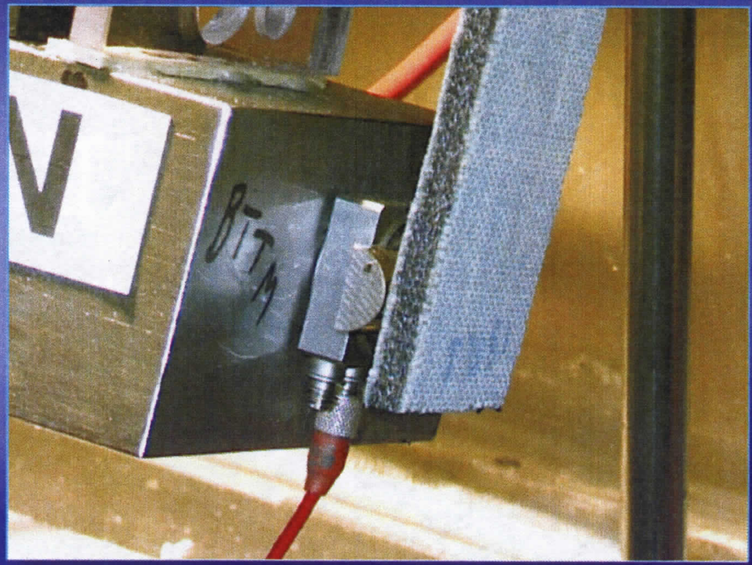
Ballistic Research Supporting the Accident Investigation

Ballistic Impact Tests on RCC Coupons



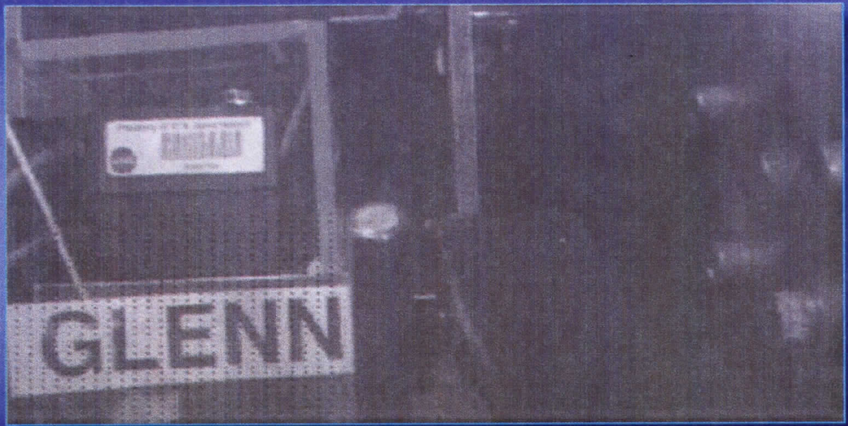
Ballistic Research Supporting the Accident Investigation

Ballistic Impact Tests on RCC Coupons



Ballistic Research Supporting the Accident Investigation

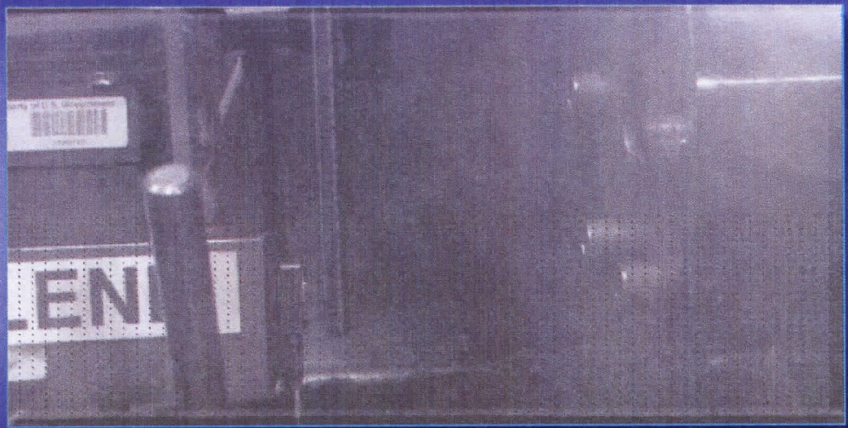
Ballistic Impact Tests on RCC Coupons



RCC Coupon Shows No Damage After 397 ft/sec Foam Impact

Ballistic Research Supporting the Accident Investigation

Ballistic Impact Tests on RCC Coupons



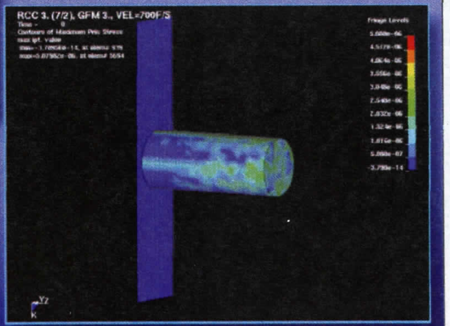
Foam Fractures RCC coupon in half at 695 ft/sec

Ballistic Research Supporting the Accident Investigation

Ballistic Impact Tests on RCC Coupons

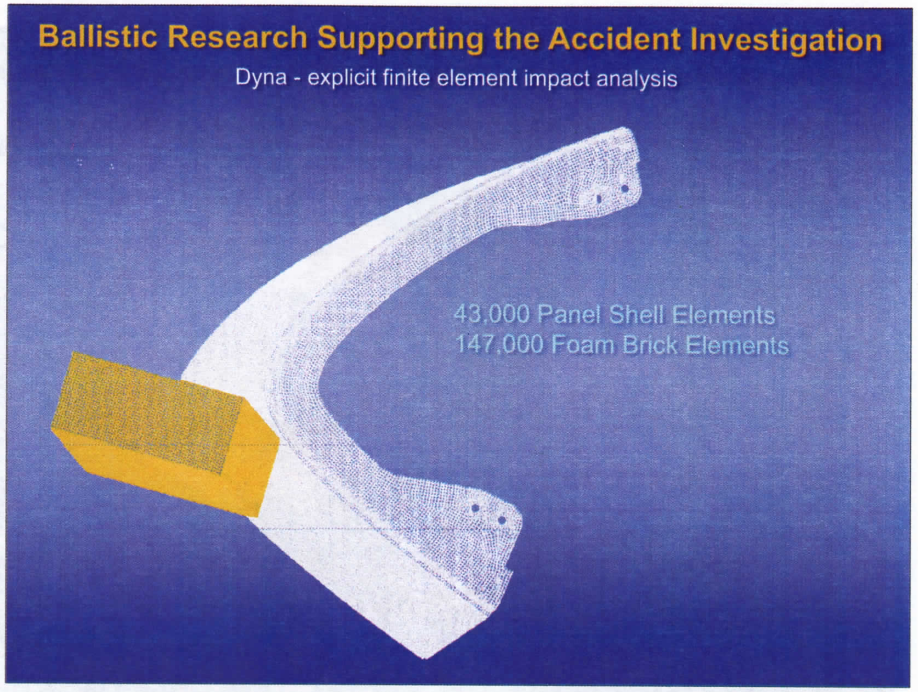
400 ft/second Impact

700 ft/second Impact

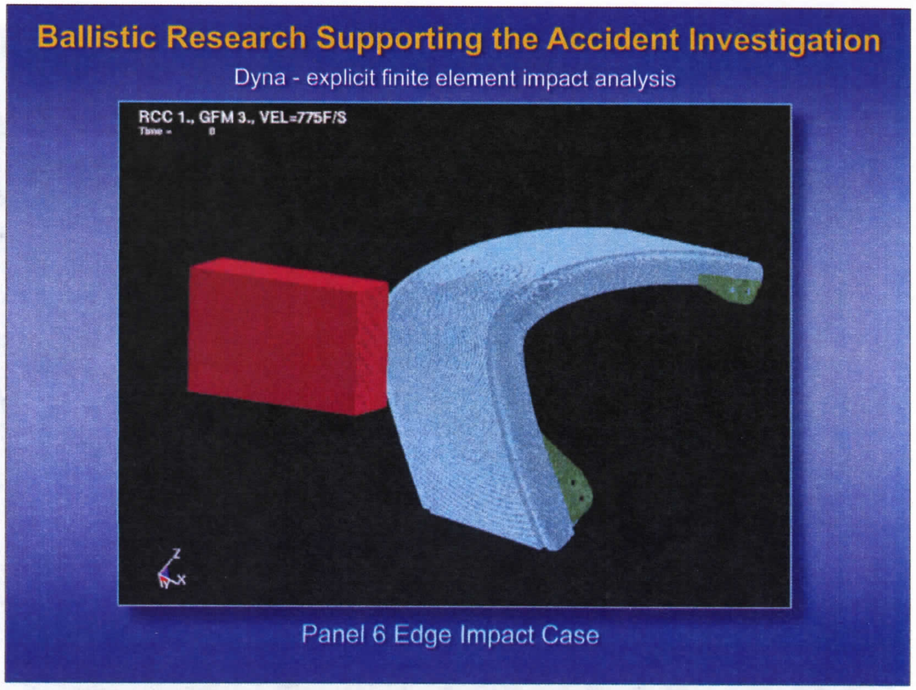


Full Scale Impact Analysis with LS Dyna


Ballistic Research Supporting the Accident Investigation
Dyna - explicit finite element impact analysis
Full Scale Panel Analysis

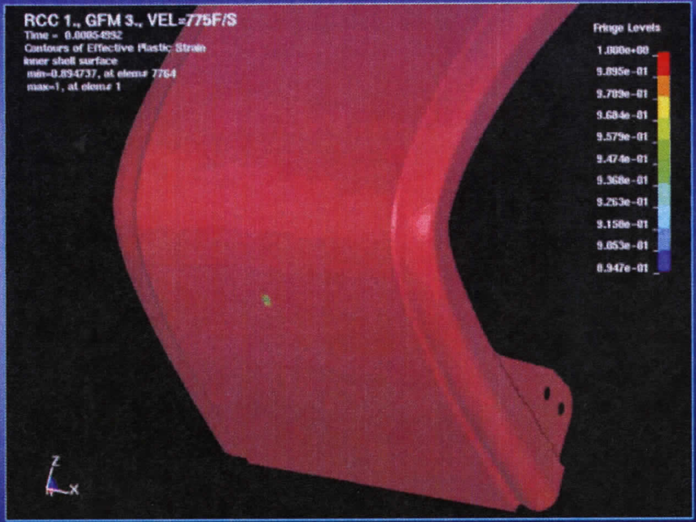

Ballistic Research Supporting the Accident Investigation
Dyna - explicit finite element impact analysis
43,000 Panel Shell Elements
147,000 Foam Brick Elements


Ballistic Research Supporting the Accident Investigation
Dyna - explicit finite element impact analysis


Ballistic Research Supporting the Accident Investigation
Dyna - explicit finite element impact analysis
RCC 1., GFM 3., VEL=775F/S
Panel 6 Edge Impact Case

Ballistic Research Supporting the Accident Investigation

Dyna - explicit finite element impact analysis



Panel 6 Edge Impact Case RCC Damage

Orbiter Leading Edge Full Scale Tests

Tests conducted at Southwest Research Institute

Orbiter Leading Edge Full Scale Tests

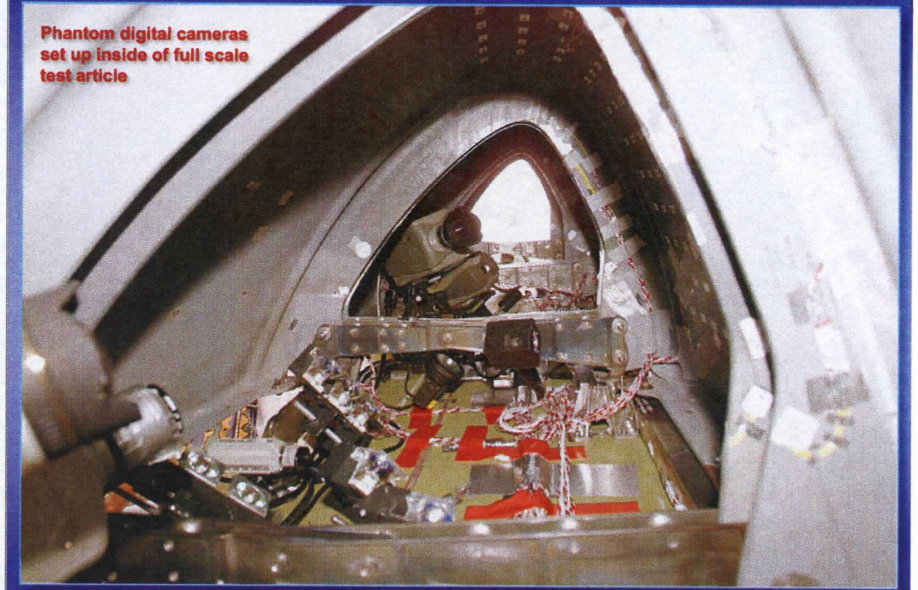
Orbiter Leading Edge Full Scale Tests

Installation of internal high speed cameras

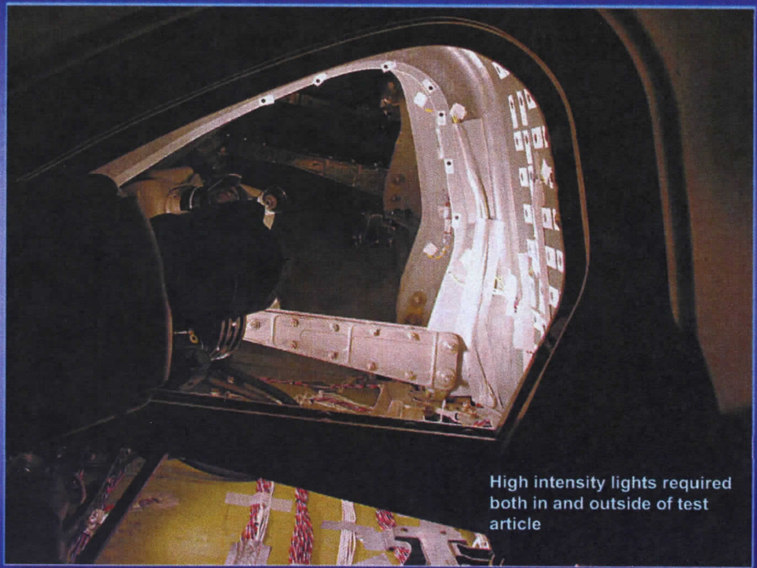
Orbiter Leading Edge Full Scale Tests

Leading edge panels mounted after camera installation

Orbiter Leading Edge Full Scale Tests



Orbiter Leading Edge Full Scale Tests



Orbiter Leading Edge Full Scale Tests

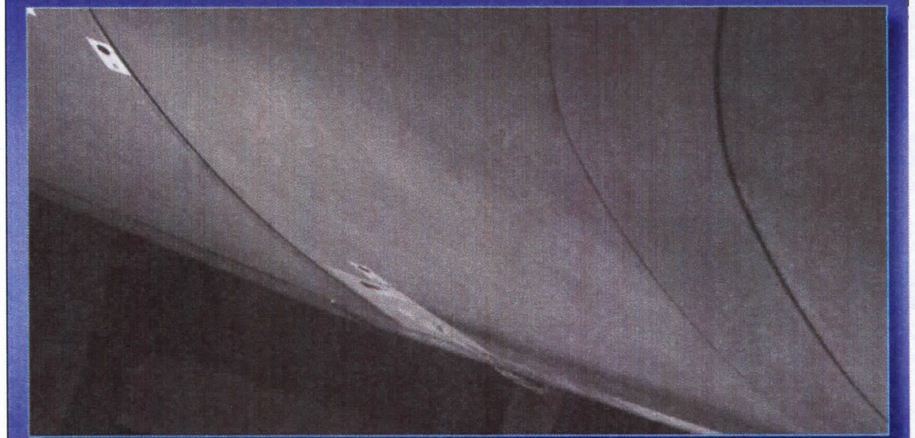
Orbiter Leading Edge Full Scale Tests

External View of RCC Panel 8 Test

Orbiter Leading Edge Full Scale Tests

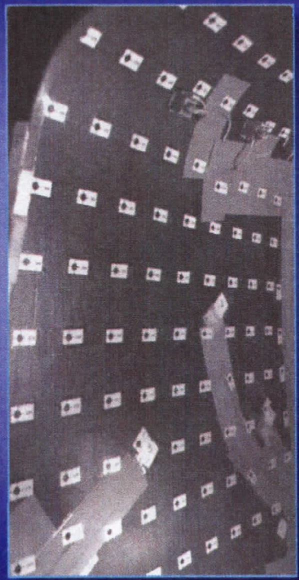
Barrel View of RCC Panel 8 Test

Orbiter Leading Edge Full Scale Tests

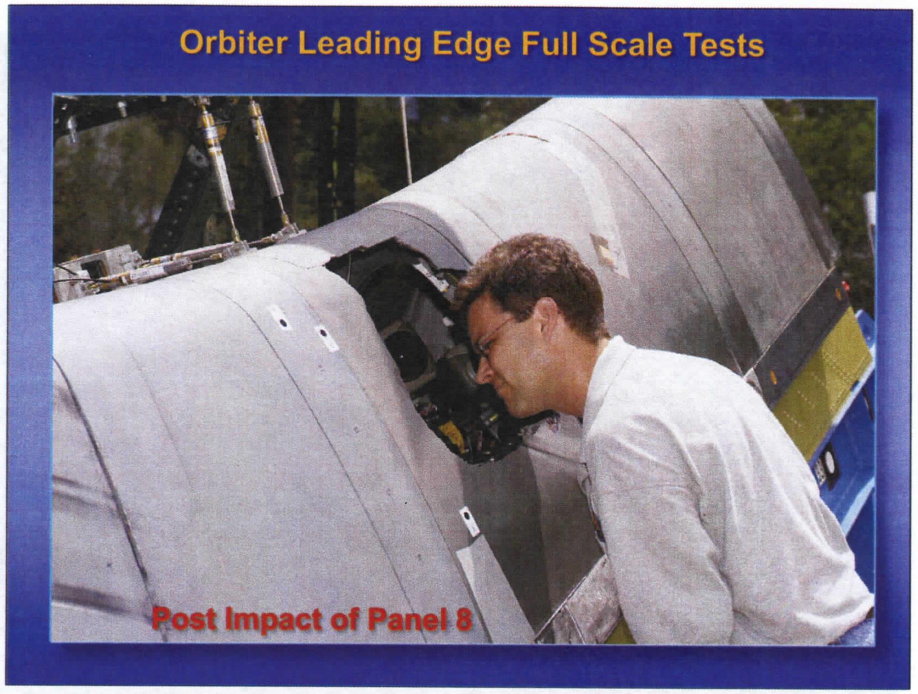


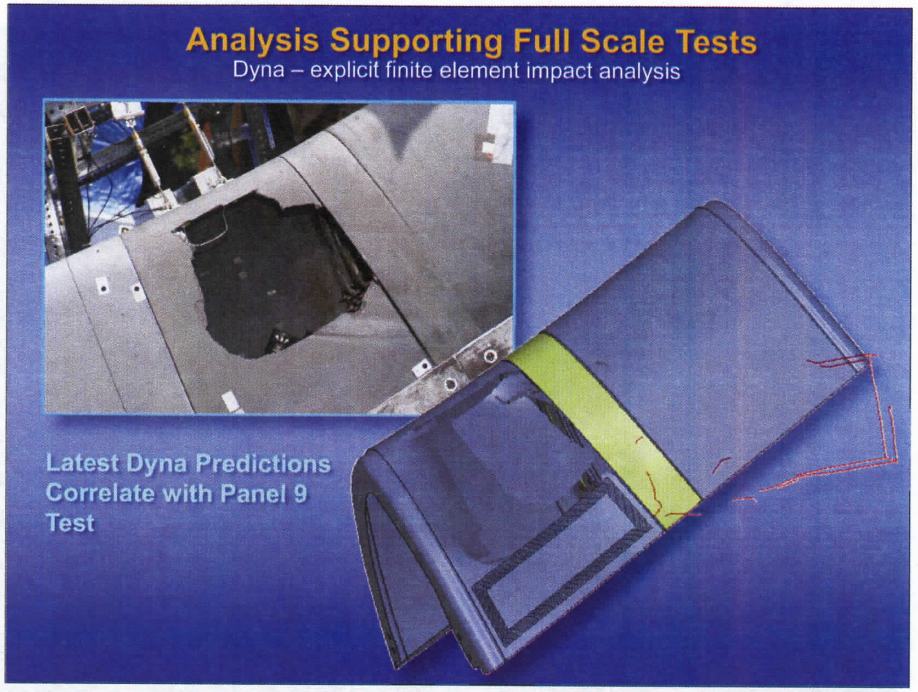
External View of RCC Panel 8 Test

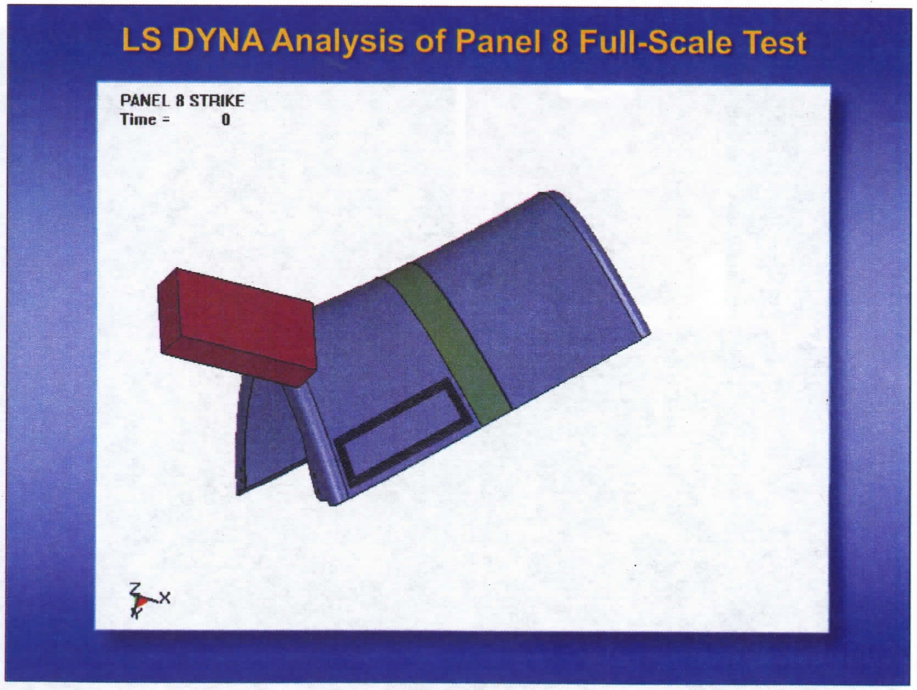
Orbiter Leading Edge Full Scale Tests



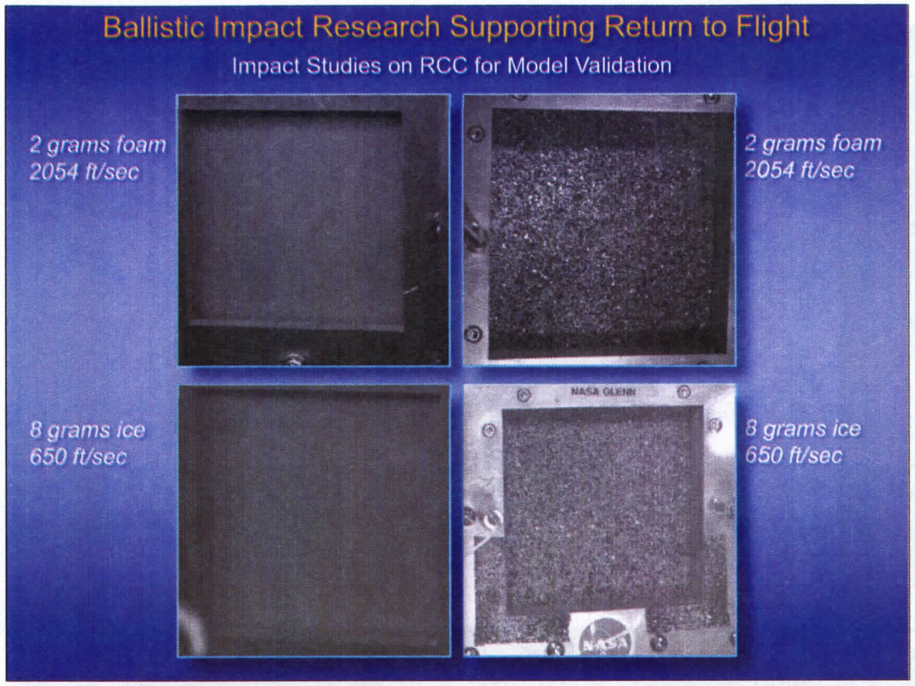
Internal View of RCC Panel 8 Test

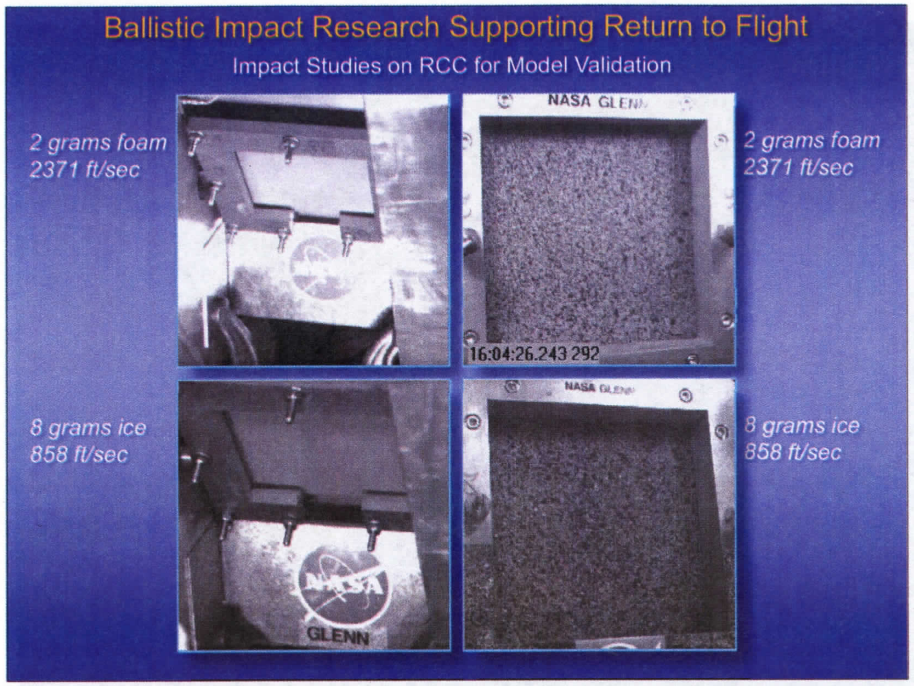

Orbiter Leading Edge Full Scale Tests
Post Impact of Panel 8


Analysis Supporting Full Scale Tests
Dyna – explicit finite element impact analysis
Latest Dyna Predictions Correlate with Panel 9 Test

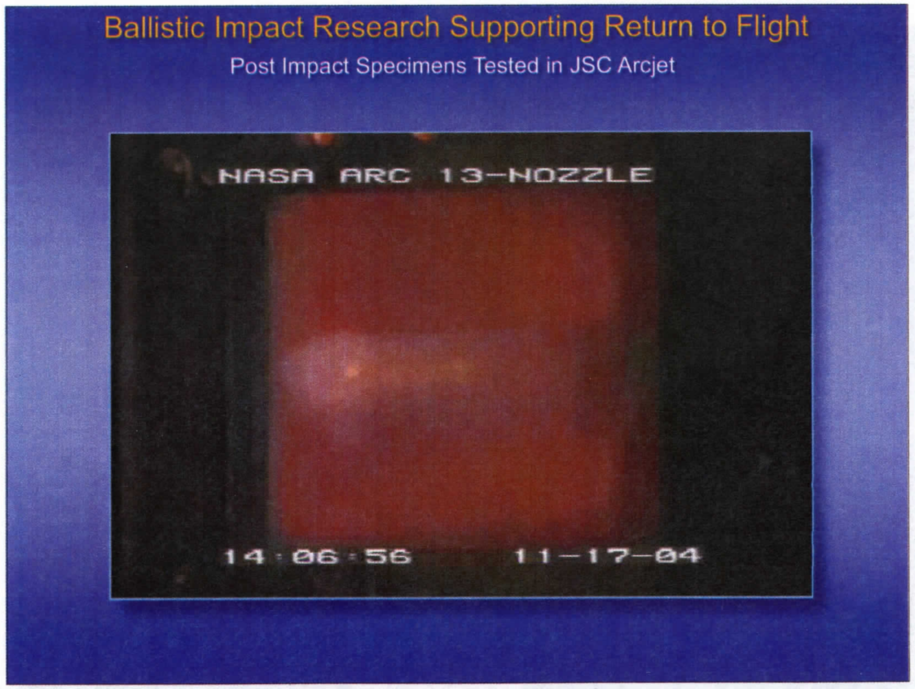

LS DYNA Analysis of Panel 8 Full-Scale Test
PANEL 8 STRIKE
Time = 0


Return to Flight


Ballistic Impact Research Supporting Return to Flight
Impact Studies on RCC for Model Validation
2 grams foam
2054 ft/sec
2 grams foam
2054 ft/sec
8 grams ice
650 ft/sec
8 grams ice
650 ft/sec
NASA GLENN


Ballistic Impact Research Supporting Return to Flight
Impact Studies on RCC for Model Validation
2 grams foam
2371 ft/sec
2 grams foam
2371 ft/sec
8 grams ice
858 ft/sec
8 grams ice
858 ft/sec
16:04:26.243 292
GLENN


Ballistic Impact Research Supporting Return to Flight
Impact Studies on RCC for Model Validation
15:12:10.174 055 S

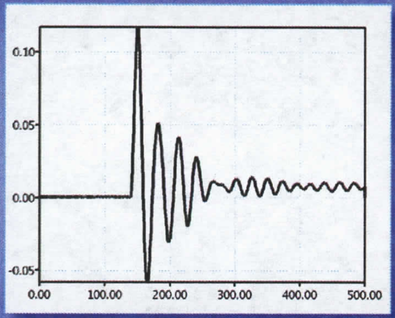

Ballistic Impact Research Supporting Return to Flight
Post Impact Specimens Tested in JSC Arcjet
NASA ARC 13-NOZZLE
14:06:56 11-17-04

Aramis Displacement Measurement System

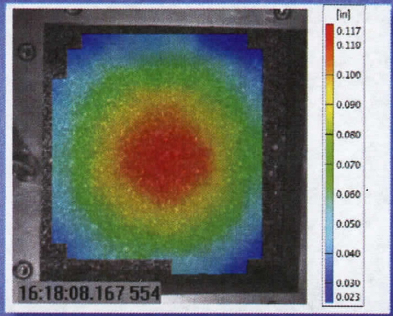
Photogrametric Technique Determines Full 3-D displacements

Aramis Displacement Measurement System

Photogrametric Technique Determines Full 3-D displacements

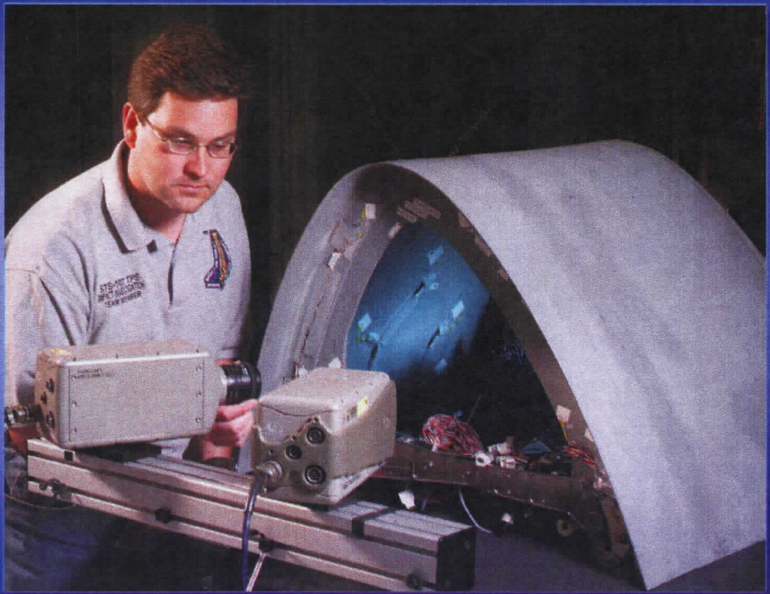


Point Displacement vs Time

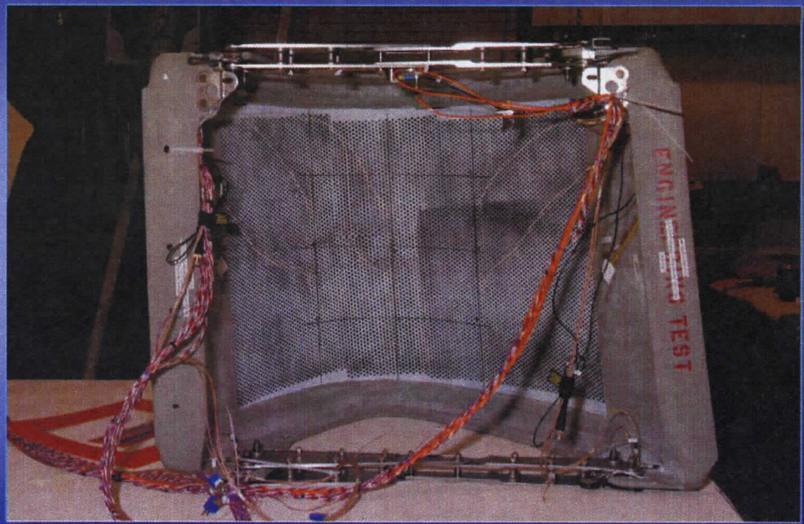


Displacement Contour Plot

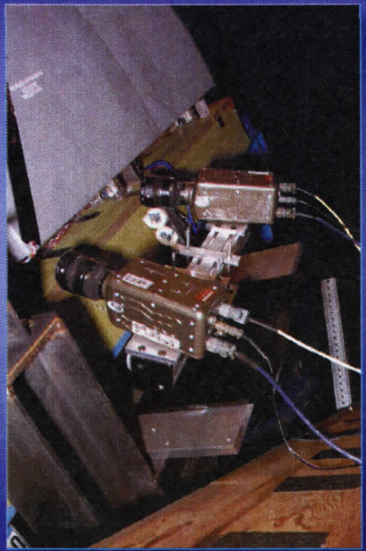
Aramis Adapted to Full-Scale Wing Leading Edge Tests

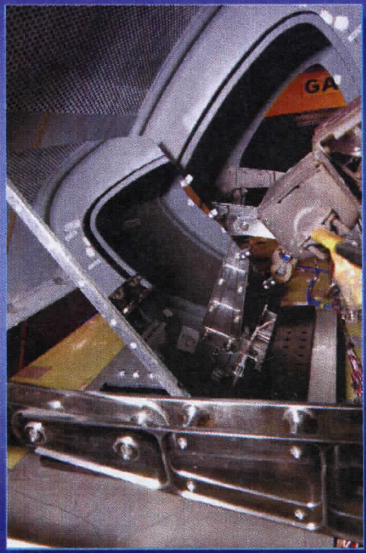


Aramis Adapted to Full-Scale Wing Leading Edge Tests



Full-Scale Leading Edge Test Setup with Aramis at SwRI



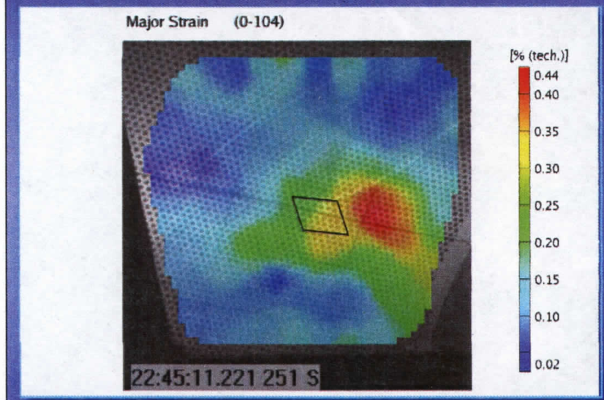


Aramis Data Validates LS DYNA Analysis Predictions

Full Field Displacements of Wing Leading Edge Impact Test

Aramis Data Validates LS DYNA Analysis Predictions

Principle Strain Comparison to Bonded Gauges



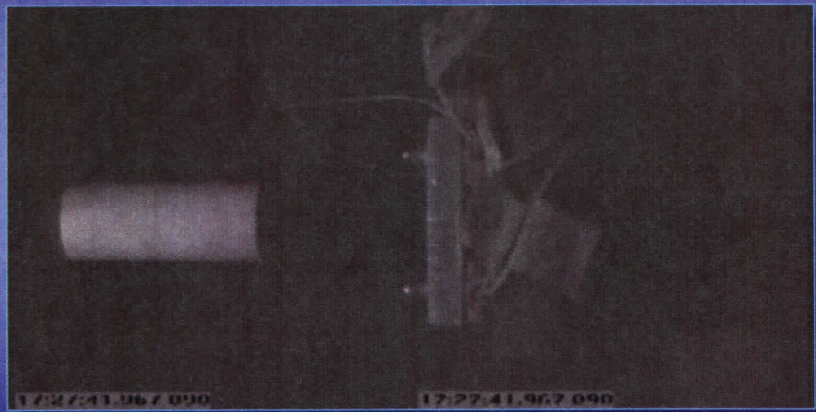
Aramis Indicated 2100-2700 Microstrain

Gauge Indicated 2100 Microstrain

Note Much Higher Amplitude 2" From Gauge

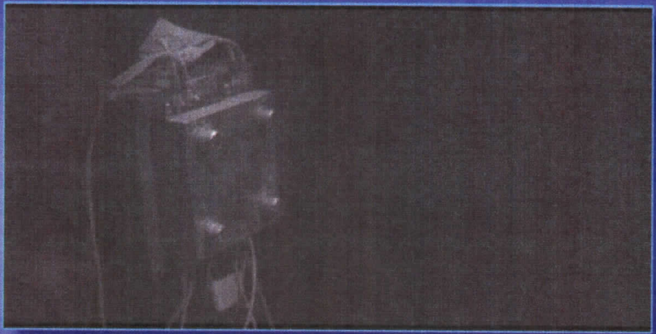
Ballistic Impact Research Supporting Return to Flight

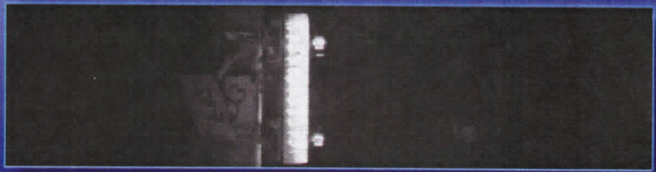
RT 455 ablator impact at approximately 300 ft/sec



Ballistic Impact Research Supporting Return to Flight

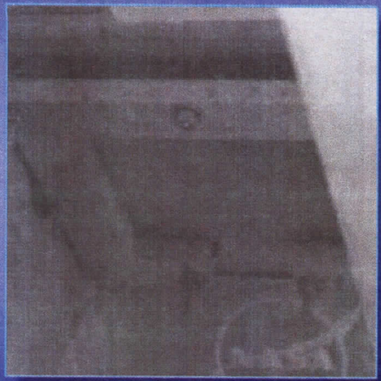
NCFI foam impact at approximately **800 ft/sec**

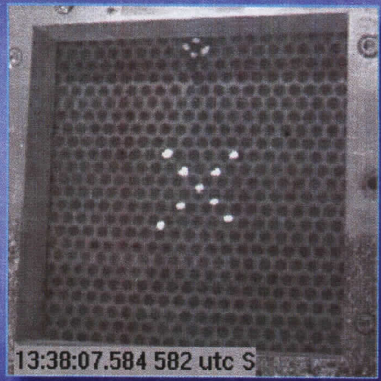




Ballistic Impact Research Supporting Return to Flight

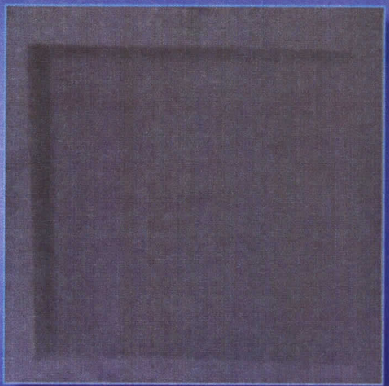
Tile Repair Putty Material Impact Testing
45 degree 1150 feet per second

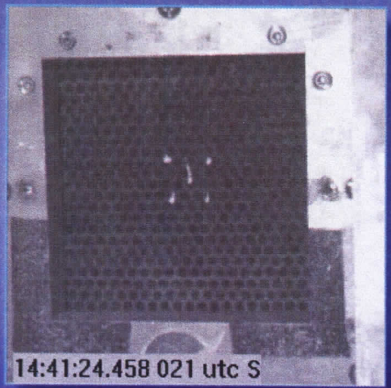




Ballistic Impact Research Supporting Return to Flight

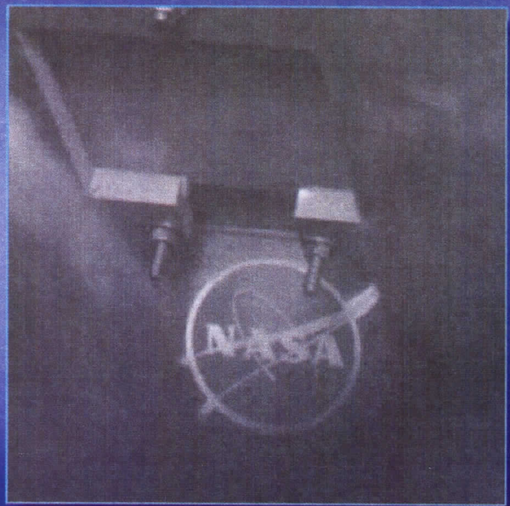
Tile Gap Filler Material Impact Testing
90 degree 648 feet per second





Ballistic Impact Research Supporting Return to Flight

Tile Gap Filler Material Impact Testing
45 degree 604 feet per second



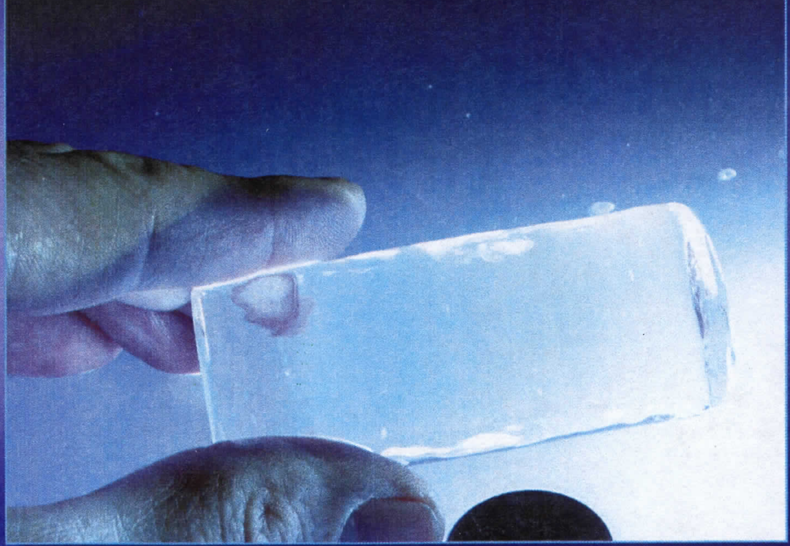
Ballistic Impact Research Supporting Return to Flight

Tile Repair Putty Material Impact Testing

Ice Formations on External Tank

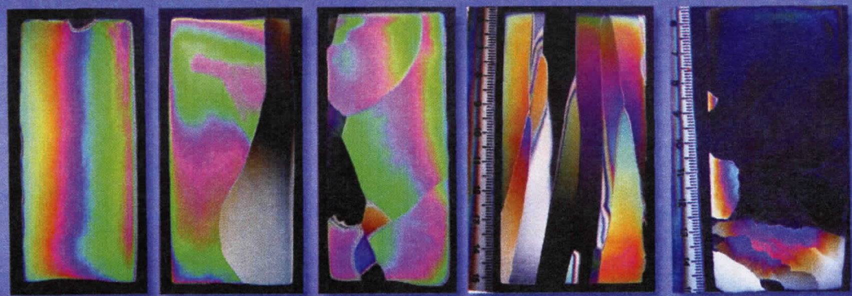
Ice Research Supporting the Return to Flight

High Density Ice (no air bubbles entrained)



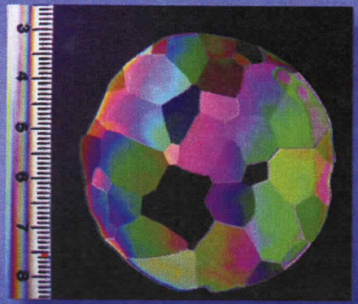
Ice Research Supporting the Return to Flight

Identification of Ice Microstructure



Ice Research Supporting the Return to Flight

Identification of Ice Microstructure

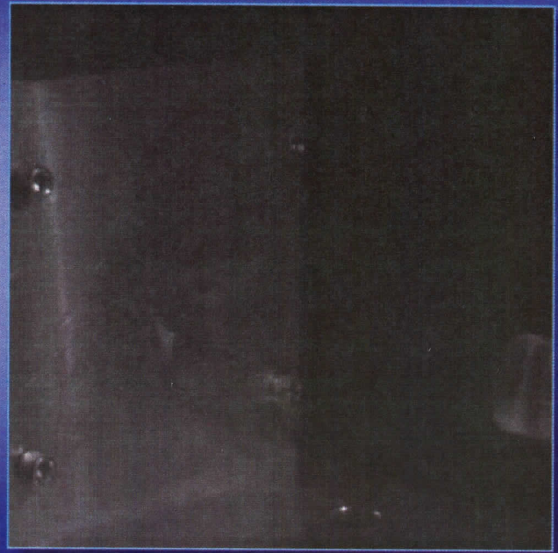


Transverse thin section

Longitudinal thin section

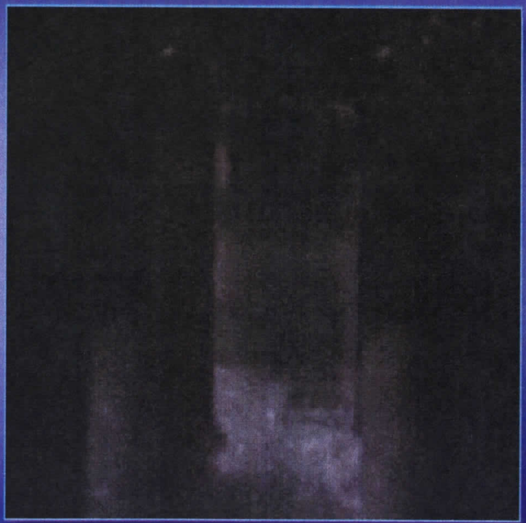
Impact Testing of Ice

Hard ice impact at approximately 800 ft/sec



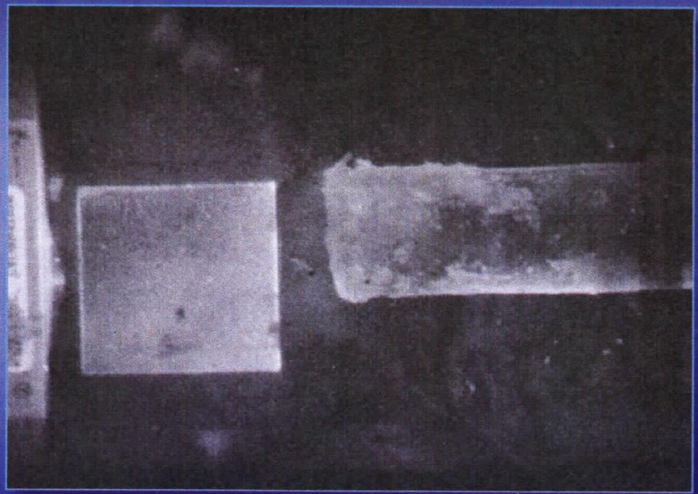
Hadland Camera Captures Fracture Wave Propagation

700 ft per second ice impact 280,000 frames per second

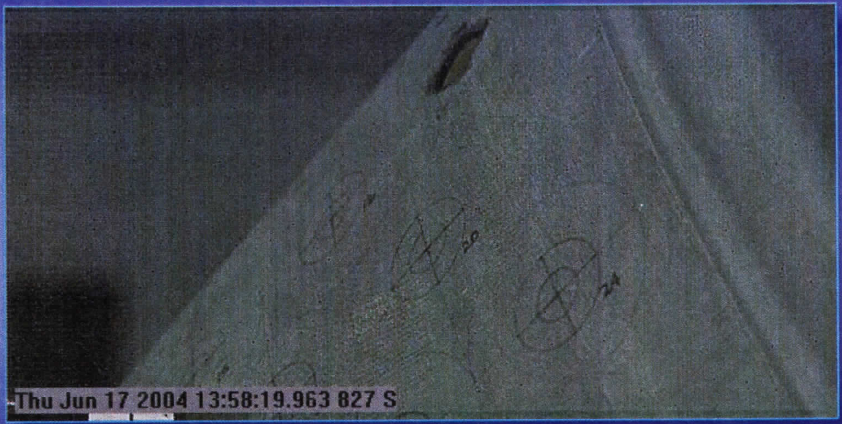


Cordin Camera Captures Fracture Wave Propagation

600 ft per second ice impact at 480,000 frames per second



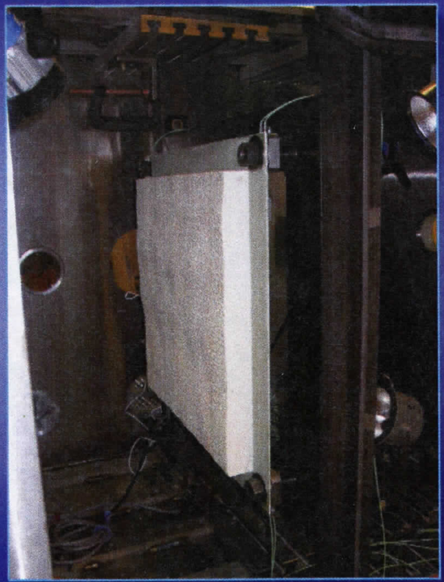
Ice Impact Testing on Full Scale Leading Edge

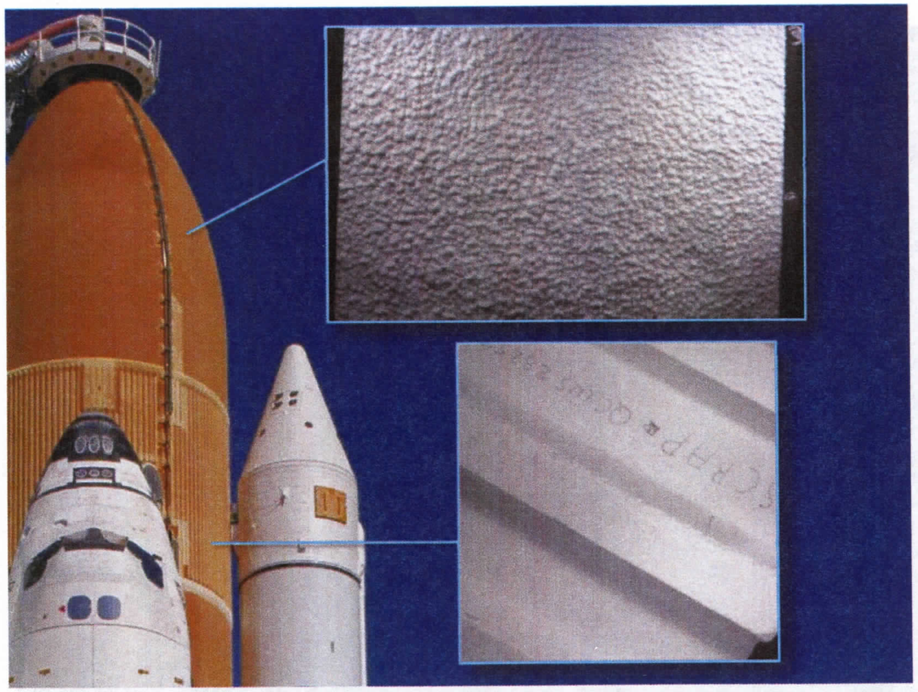


External Tank Impact Testing

Ballistic Impact Research Supporting Return to Flight

External Tank Impact Test Article with Acreage Foam



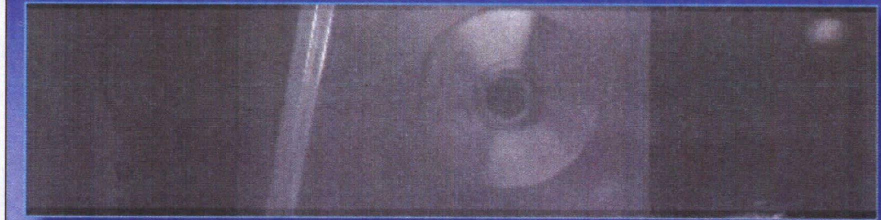


Orbiter Windows Impact Testing

Orbiter Windows Testing at NASA GRC

Ballistic Impact Research Supporting Return to Flight

NCFI Foam Impact Test on Orbiter Window



Rear View

Side View

Ballistic Impact Research Supporting Return to Flight

NCFI Foam Impact Test on Orbiter Window

Ballistic Impact Research Supporting Return to Flight

Particulates from Booster Separation Motors a Concern with Windows

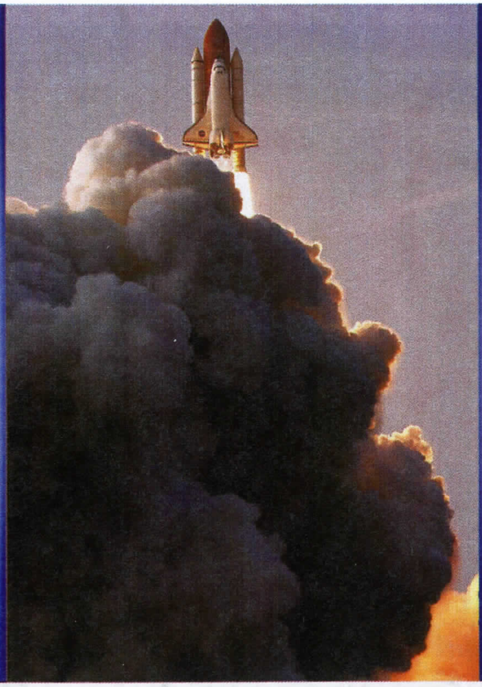
Ballistic Impact Research Supporting Return to Flight

Aluminum Oxide particles impact orbiter windows

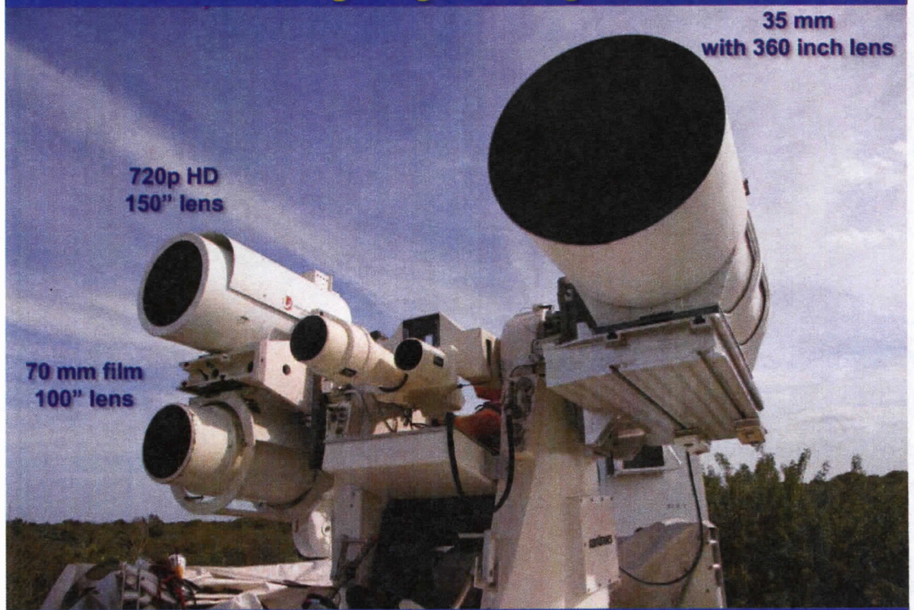
70 degree, 127 ft/sec

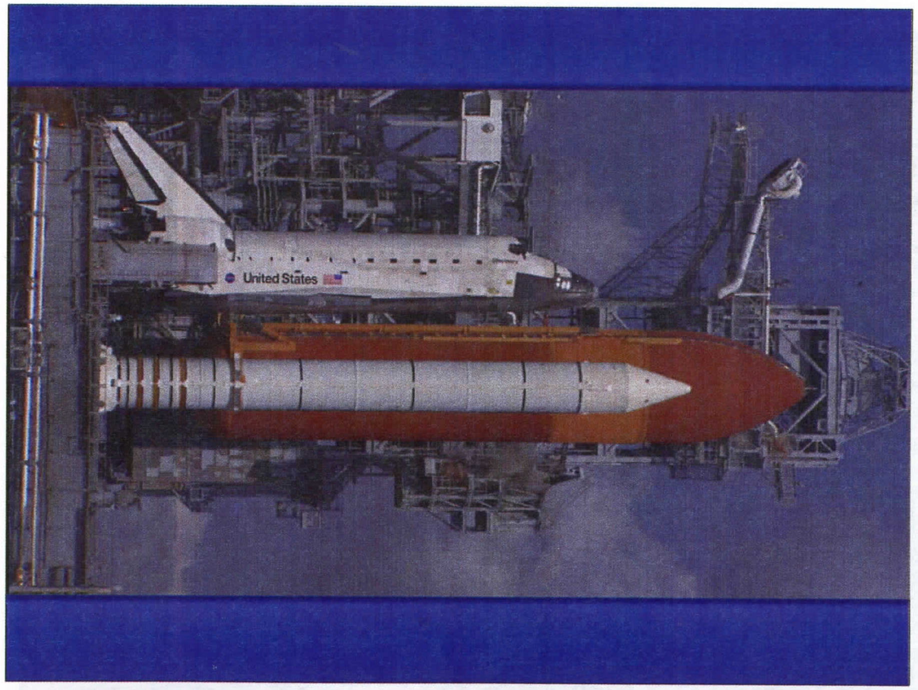
90 degree 359 ft/sec

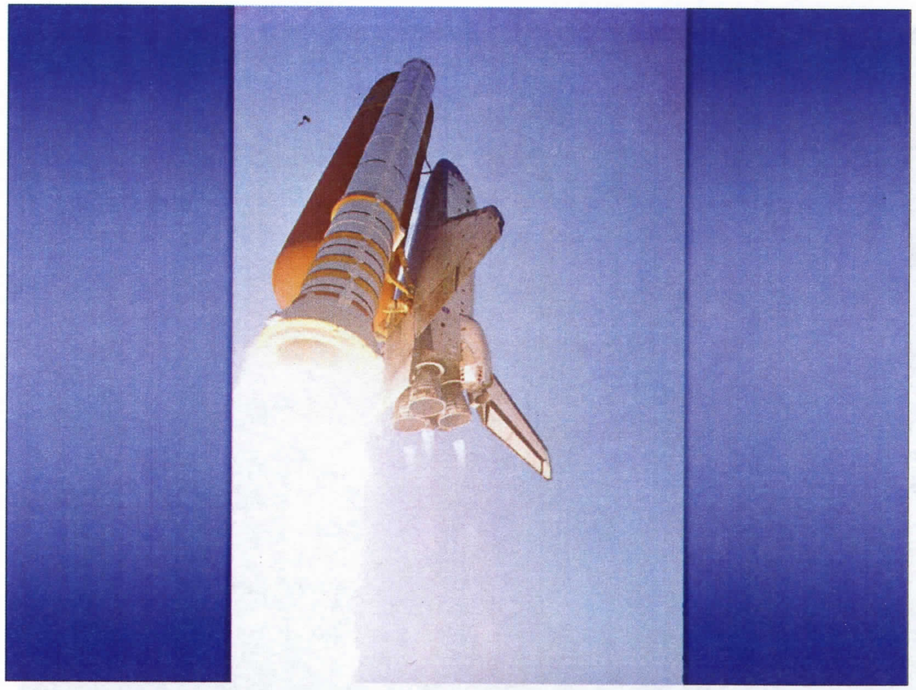
50 degree 118 ft/sec



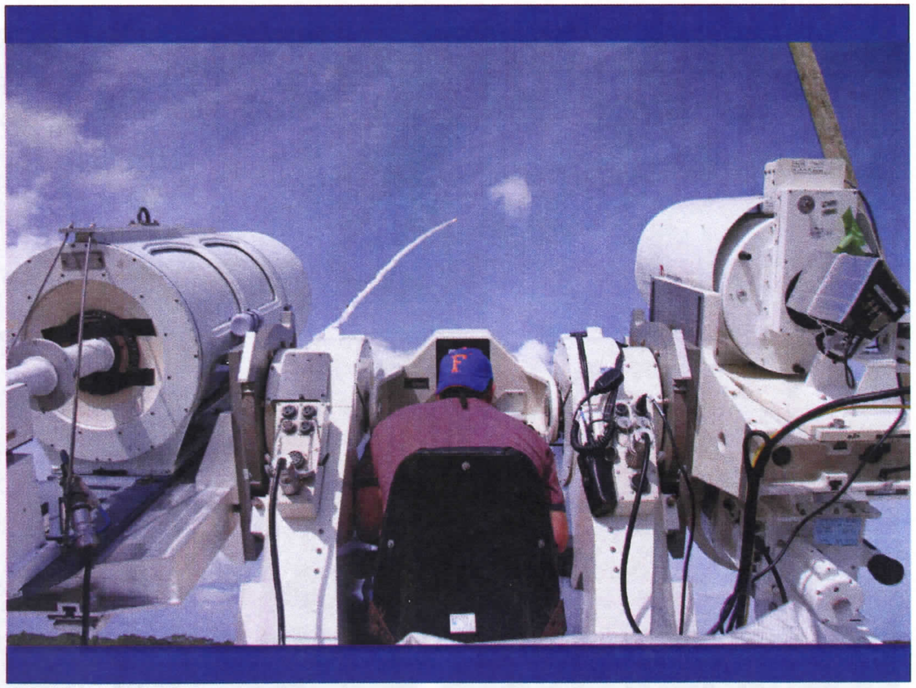
Long Range Tracking Site

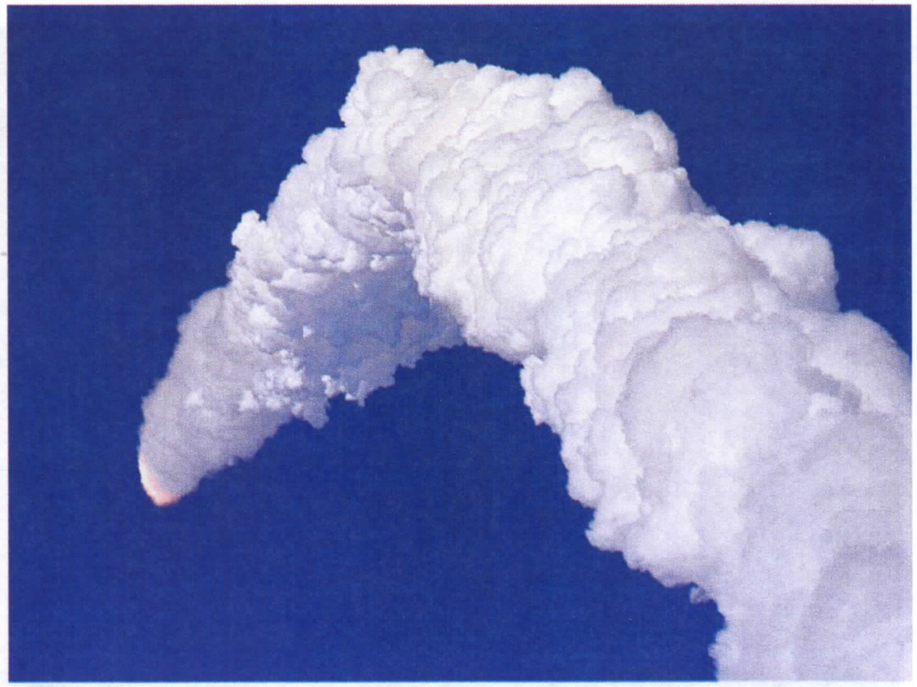


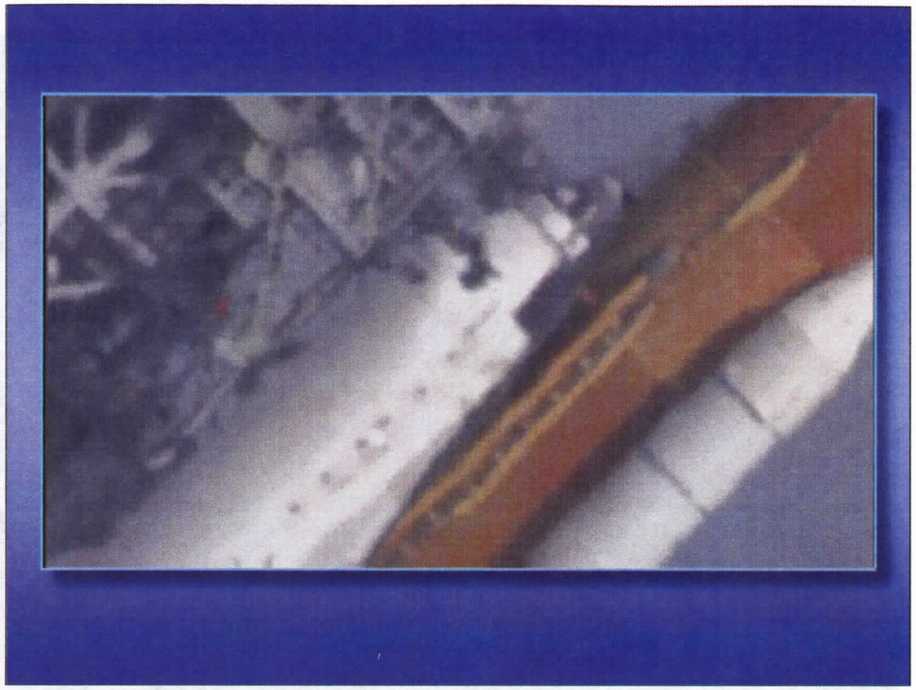

United States

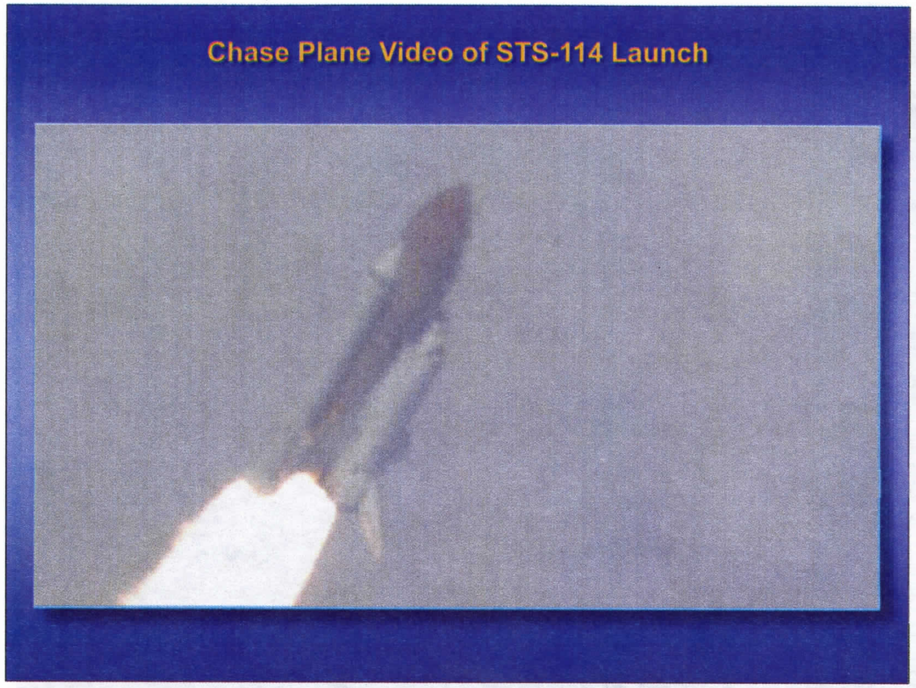


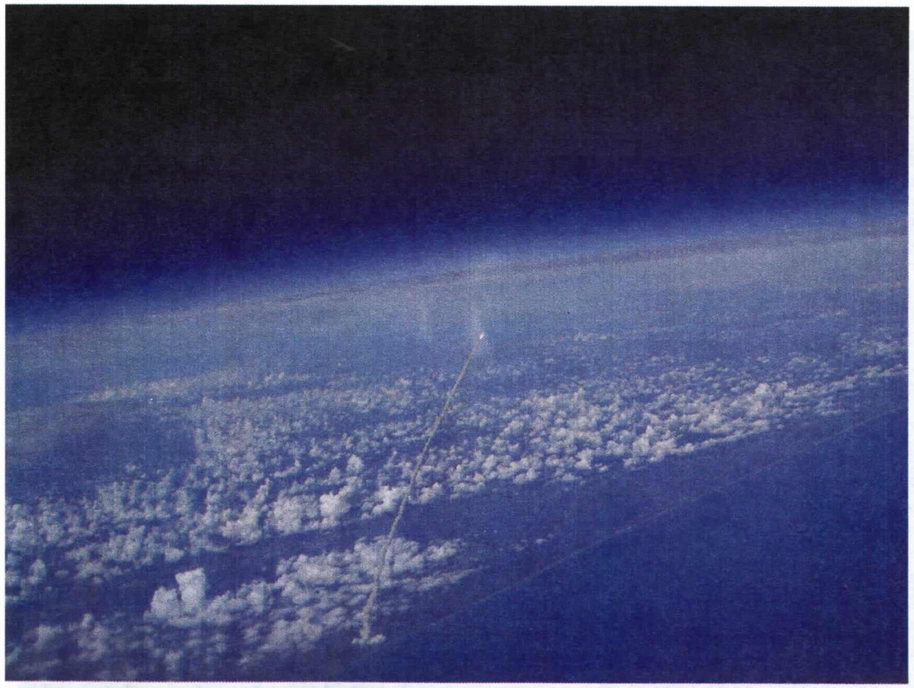

Long Range Tracking Site
720p HD
150" lens
35 mm
with 360 inch lens
70 mm film
100" lens

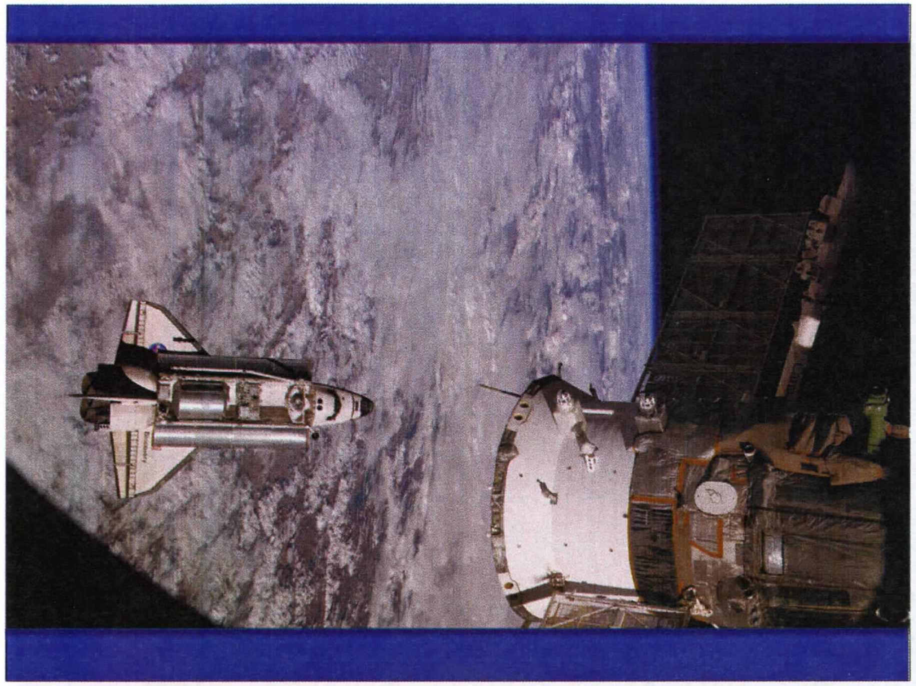


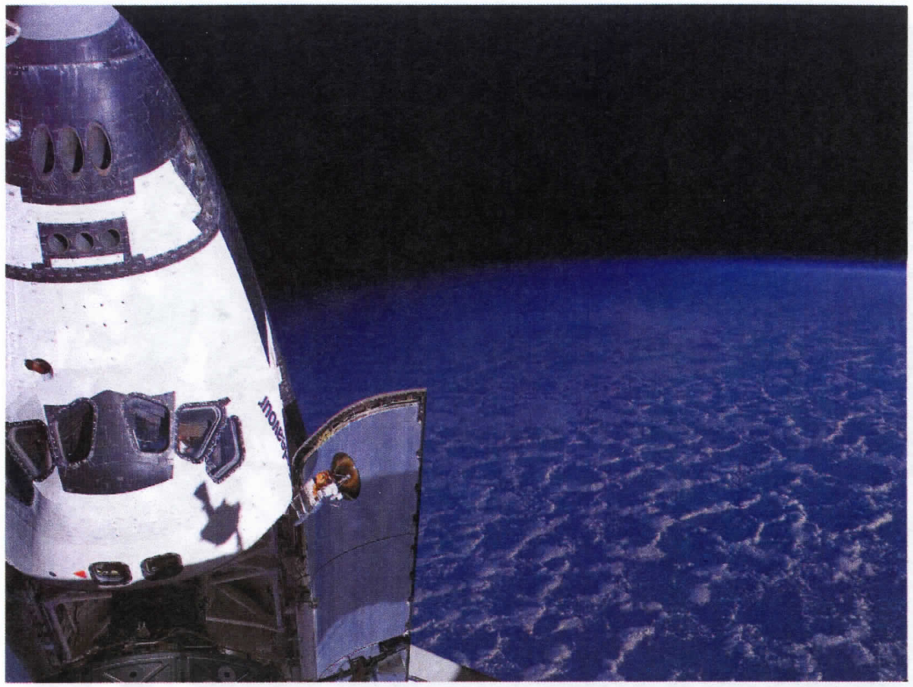


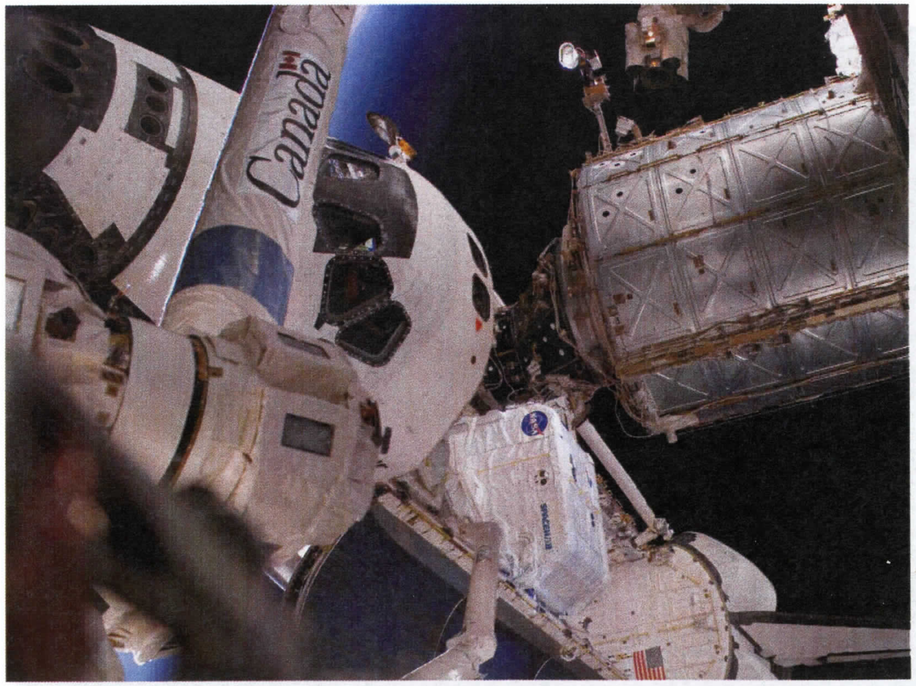


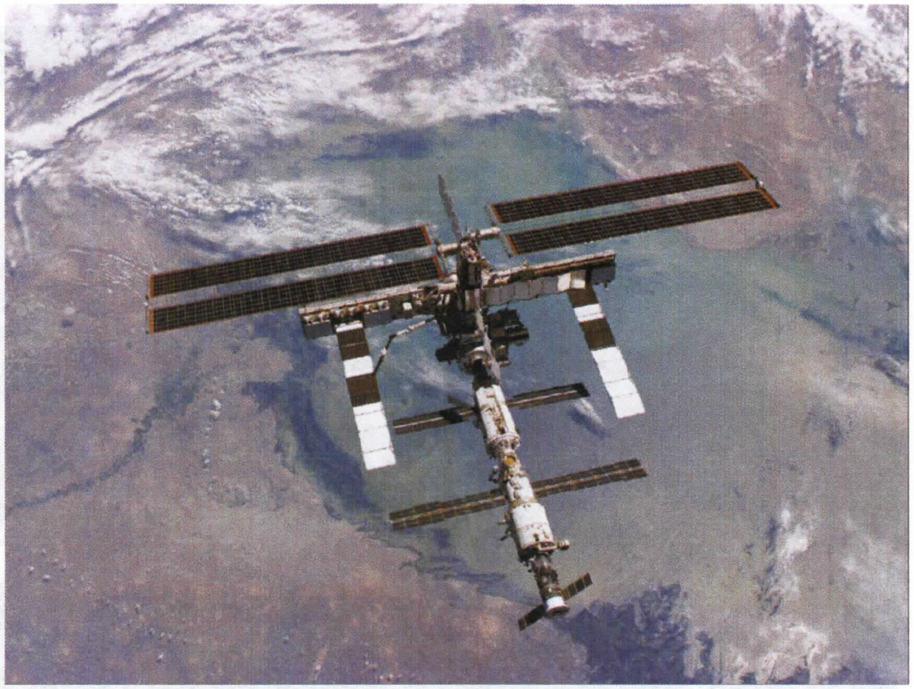
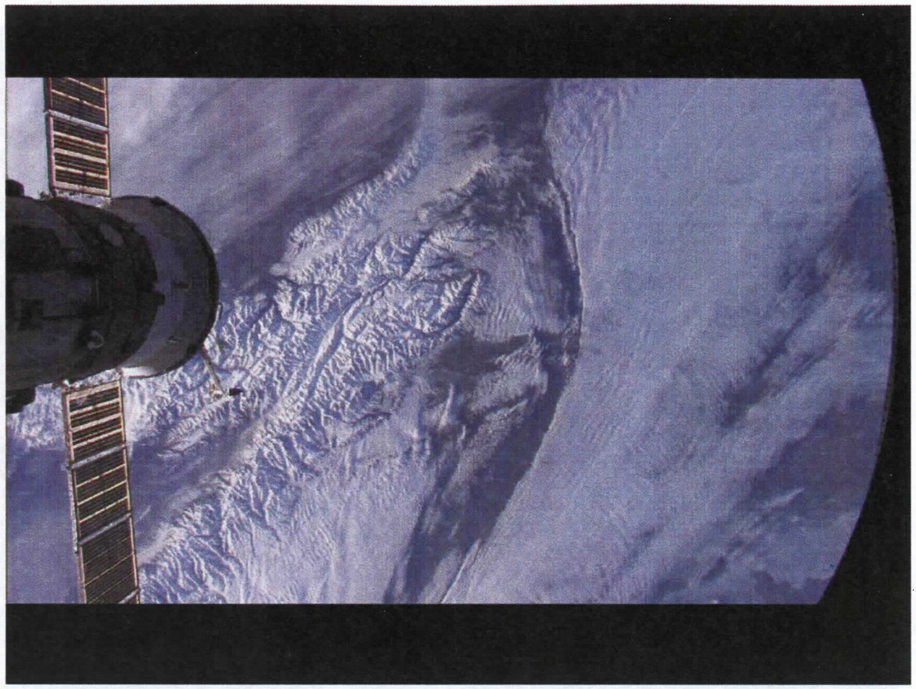

Chase Plane Video of STS-114 Launch

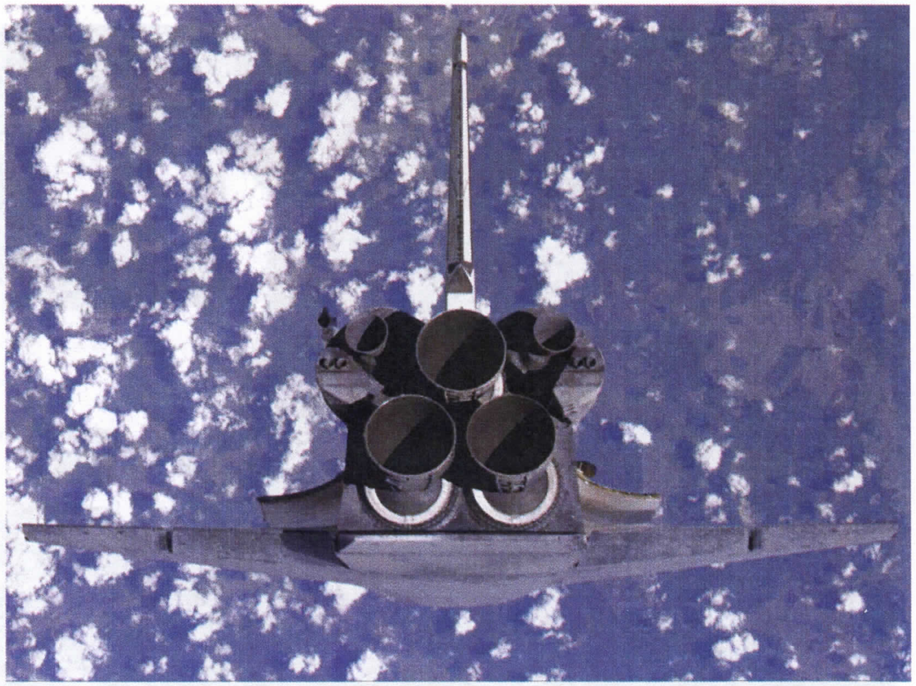


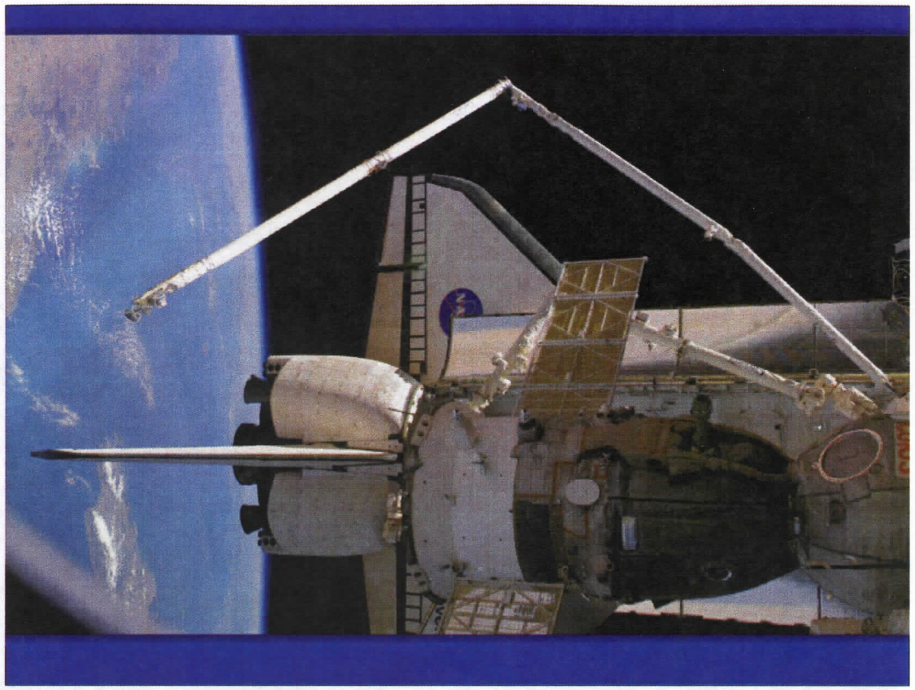


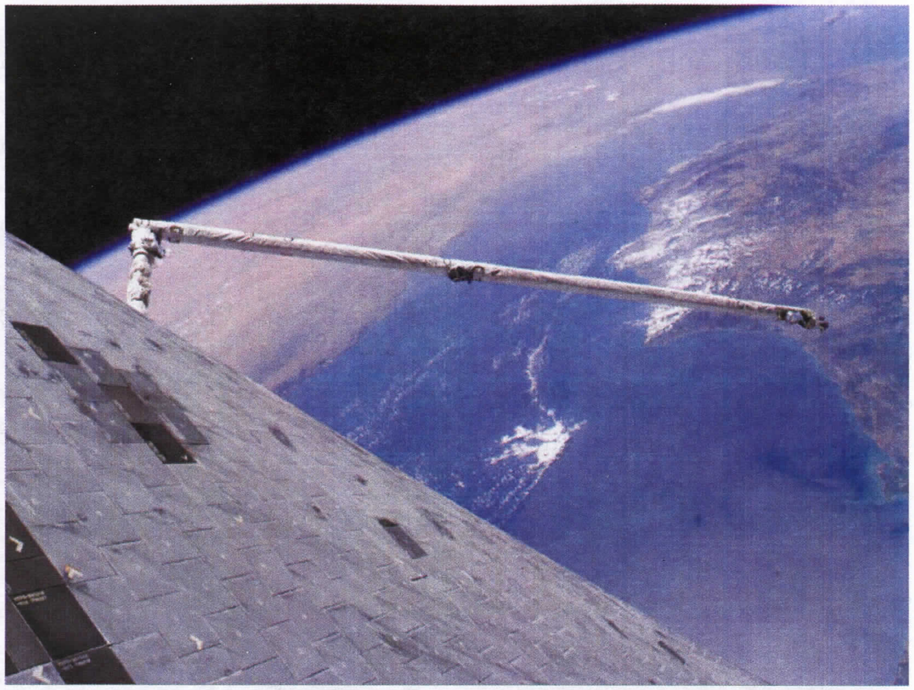


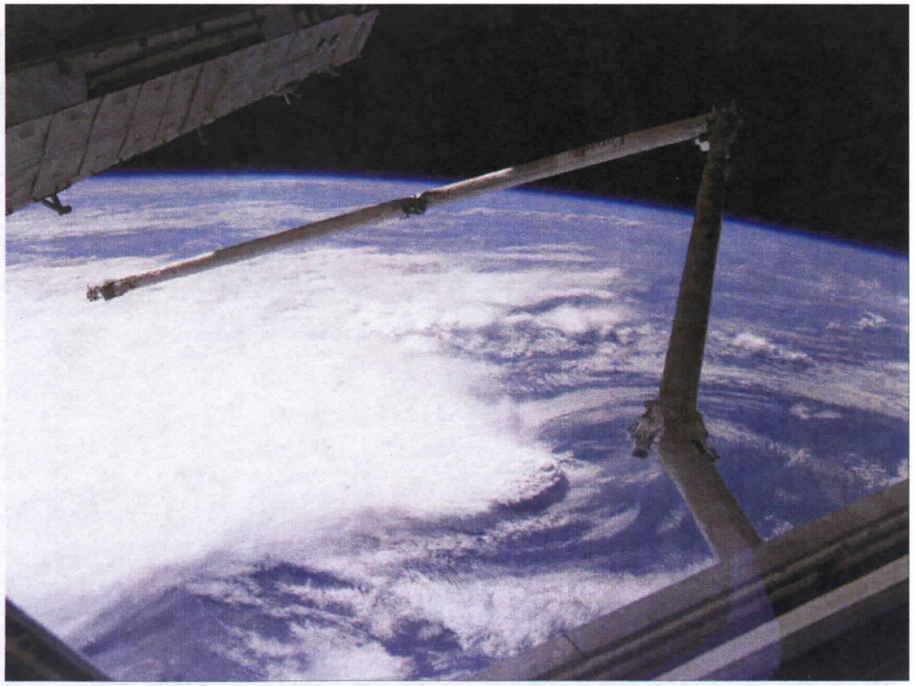

Canada

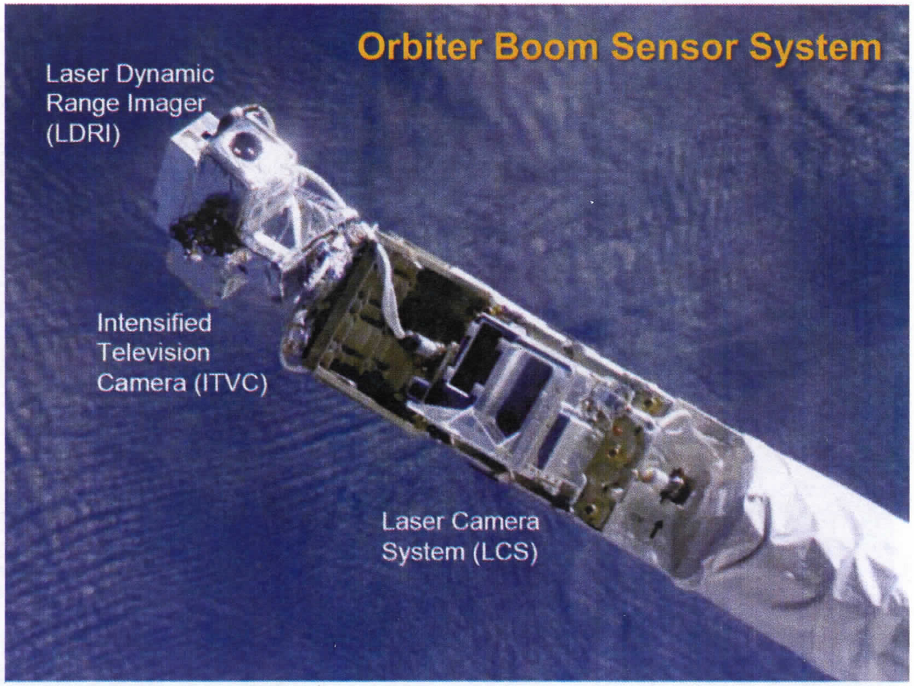



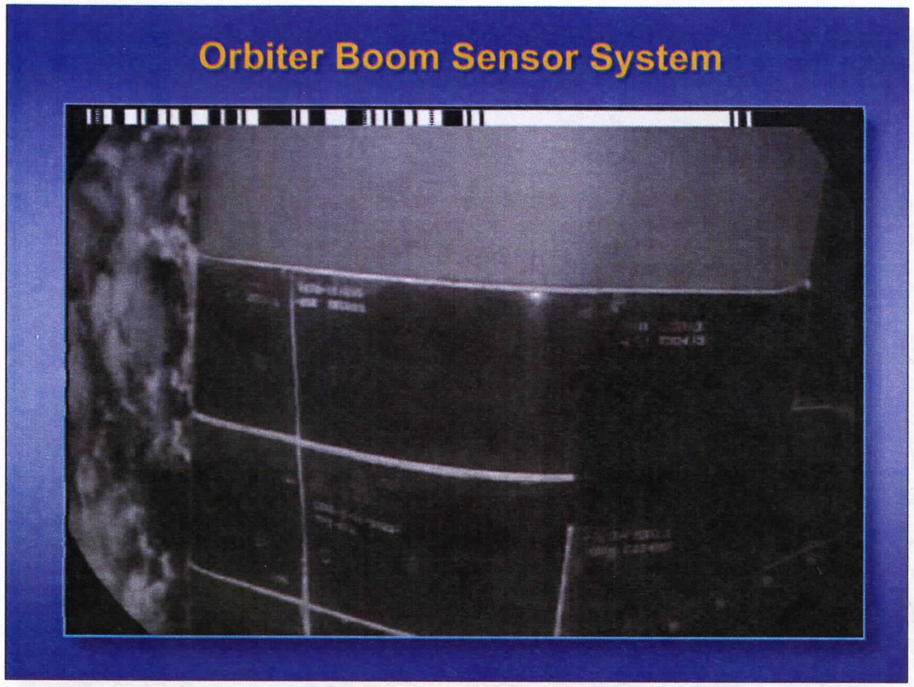


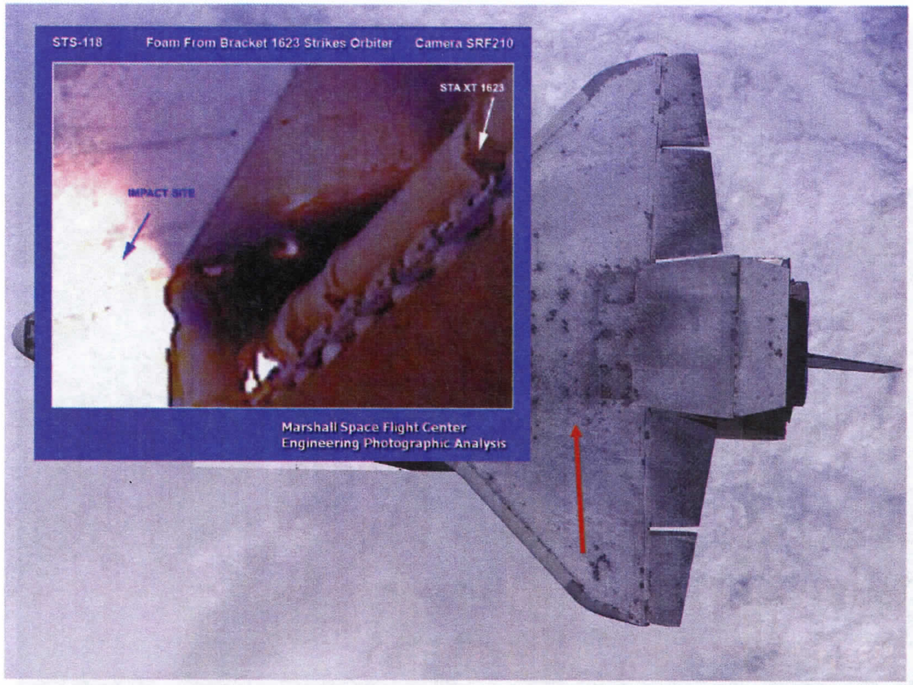


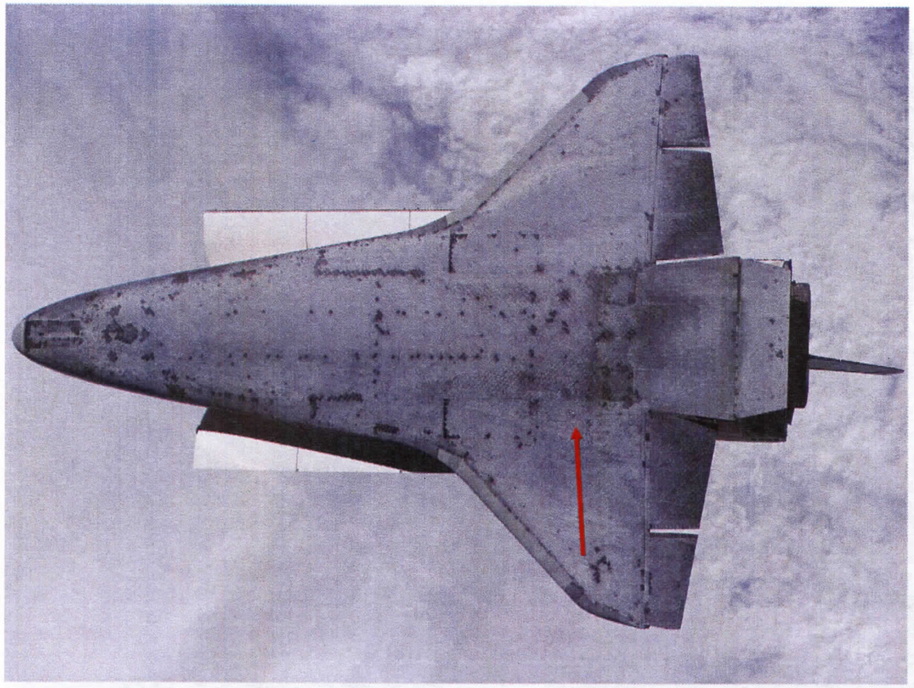


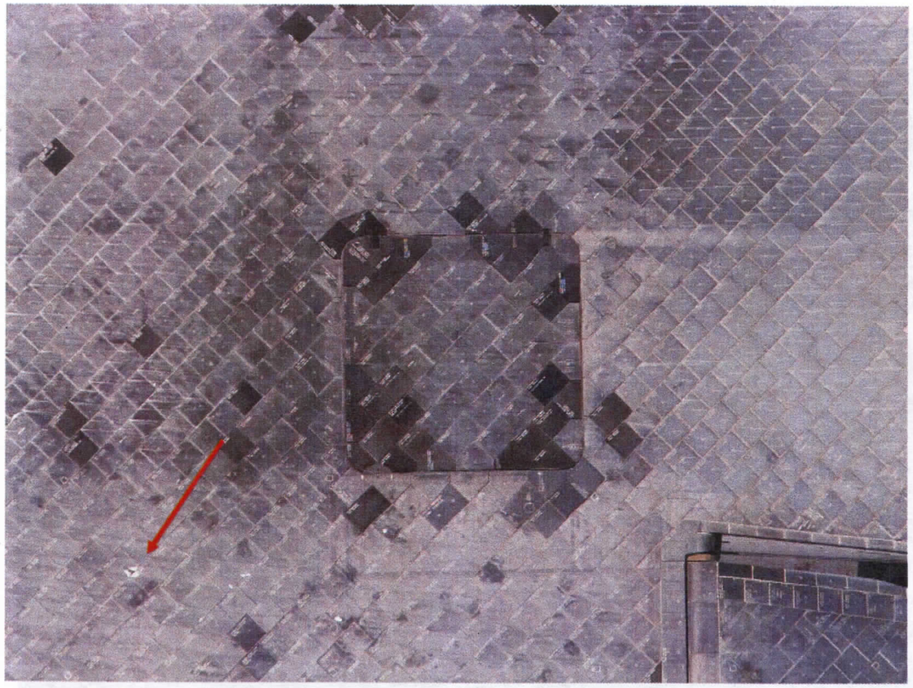


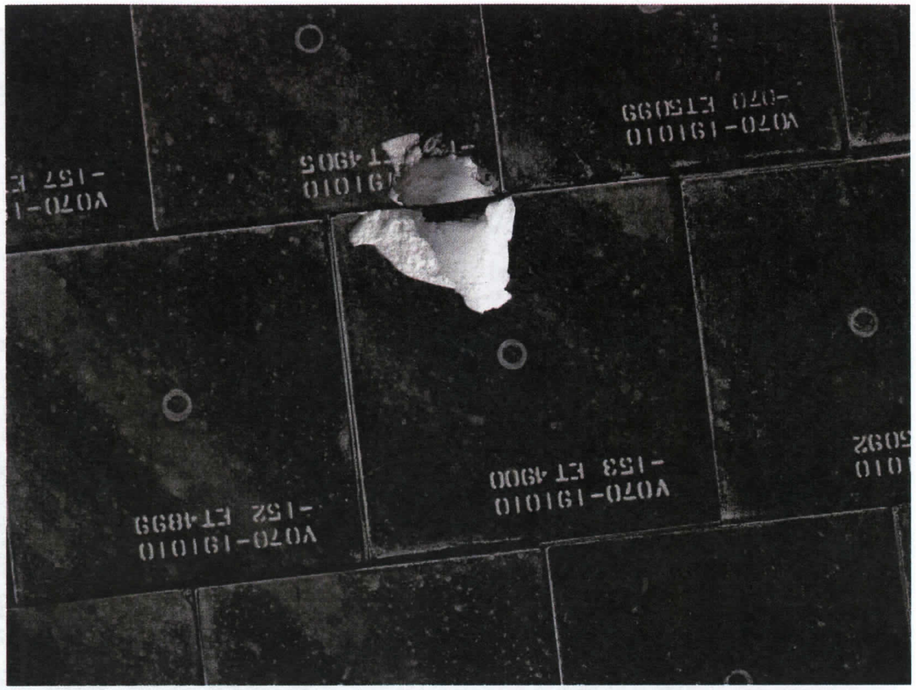

Orbiter Boom Sensor System
Laser Dynamic
Range Imager
(LDRI)
Intensified
Television
Camera (ITVC)
Laser Camera
System (LCS)

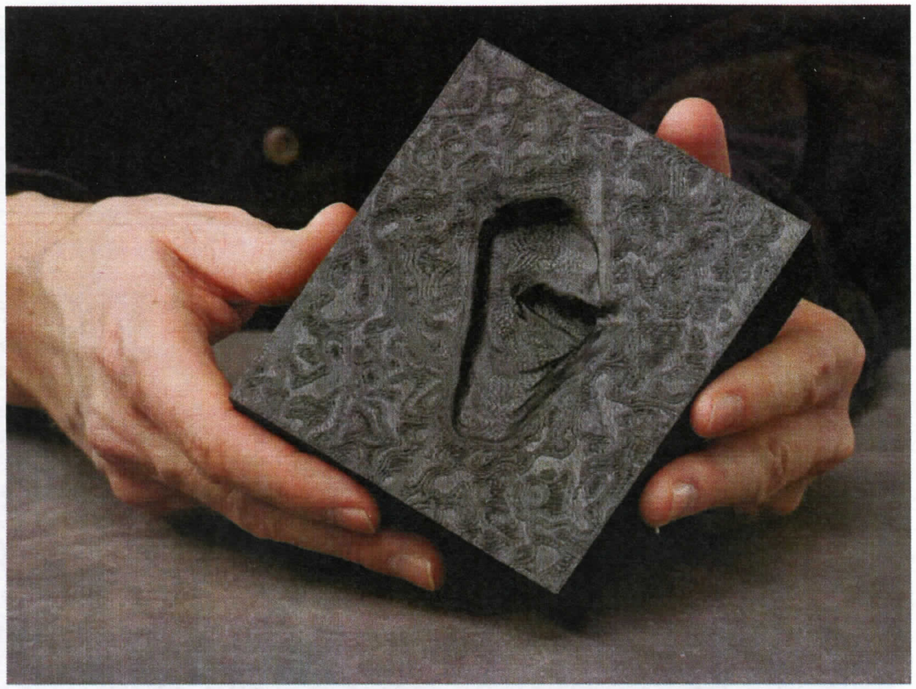

Orbiter Boom Sensor System


STS-118
Foam From Bracket 1623 Strikes Orbiter
Camera SRF210
STA XT 1623
IMPACT SITE
Marshall Space Flight Center
Engineering Photographic Analysis

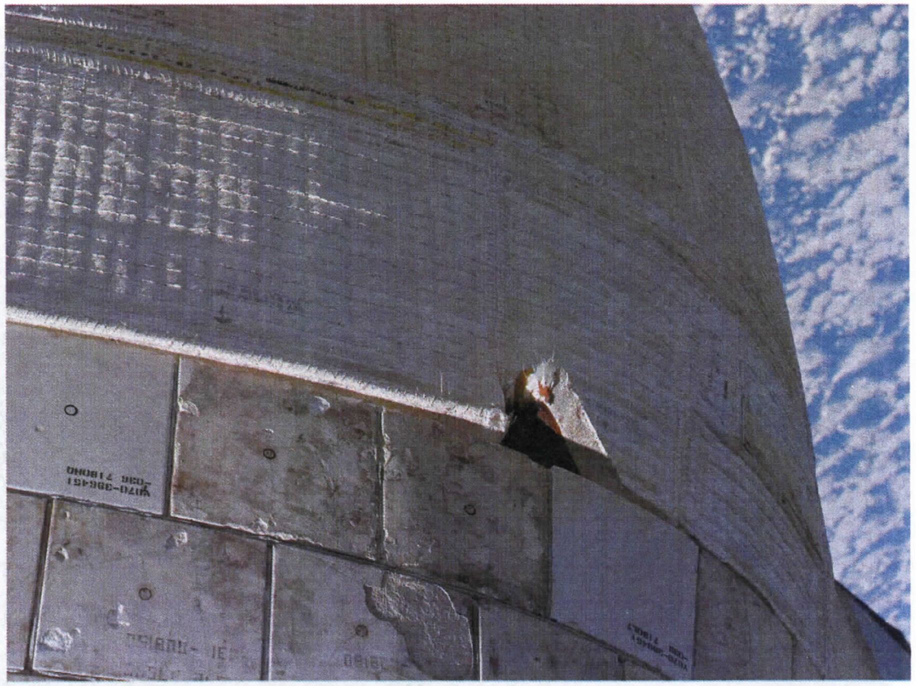


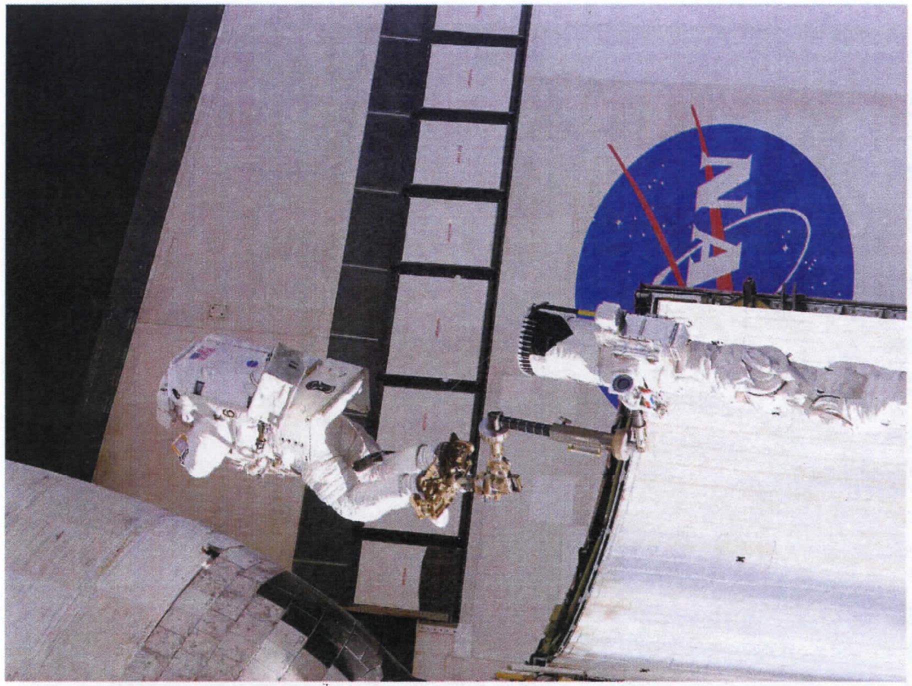


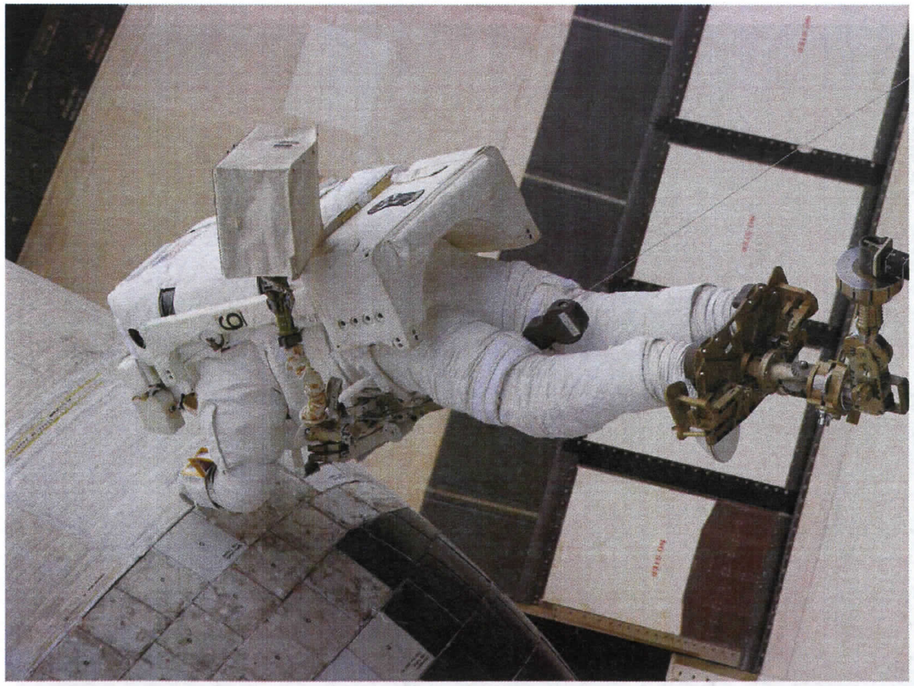

V070-191010
-070 ET5099
V070-191010
-153 ET4900
V070-191010
-152 ET4899

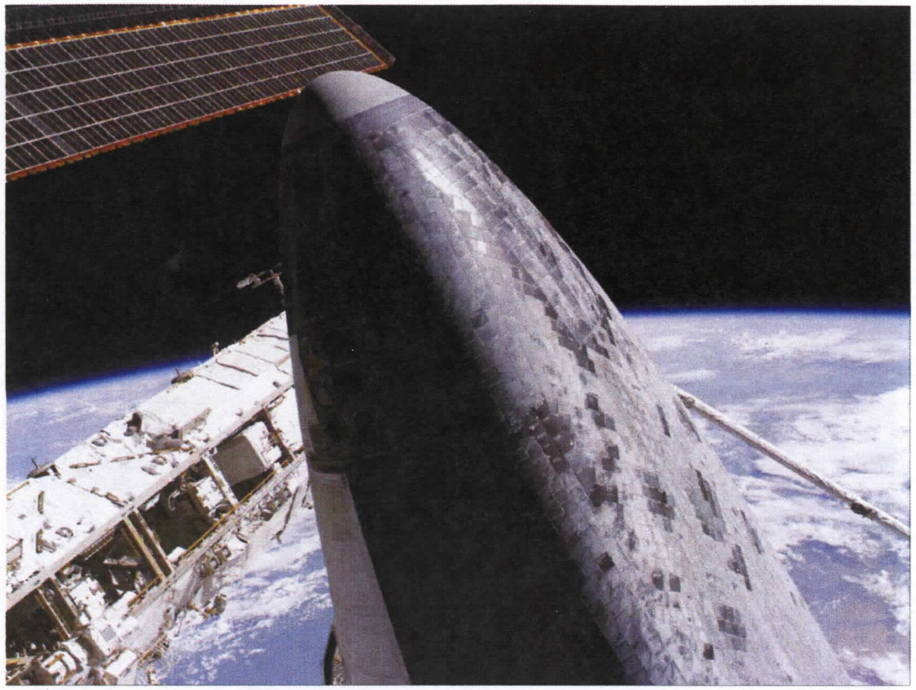


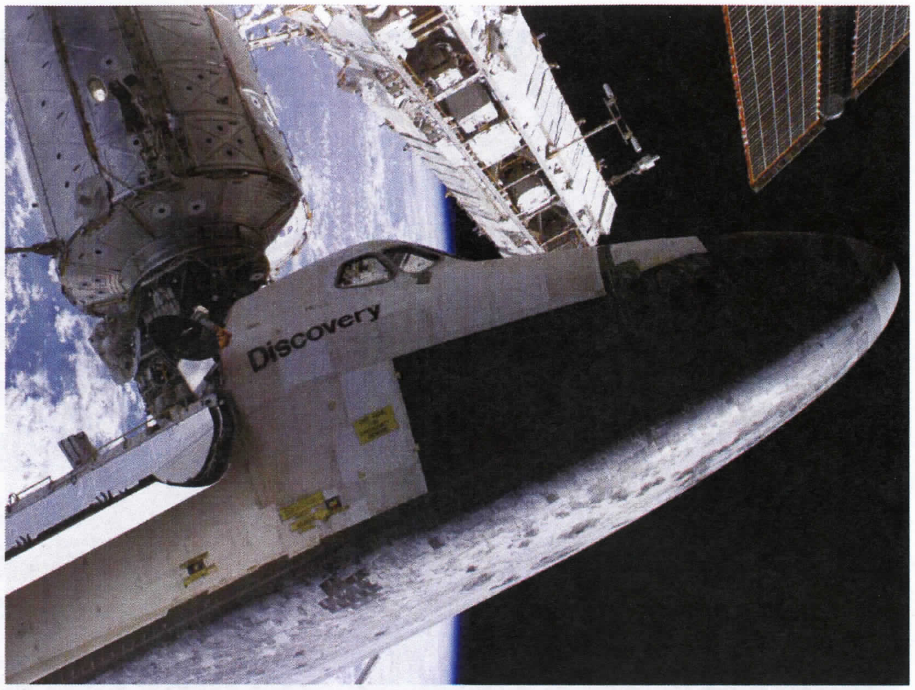

191010
T4905

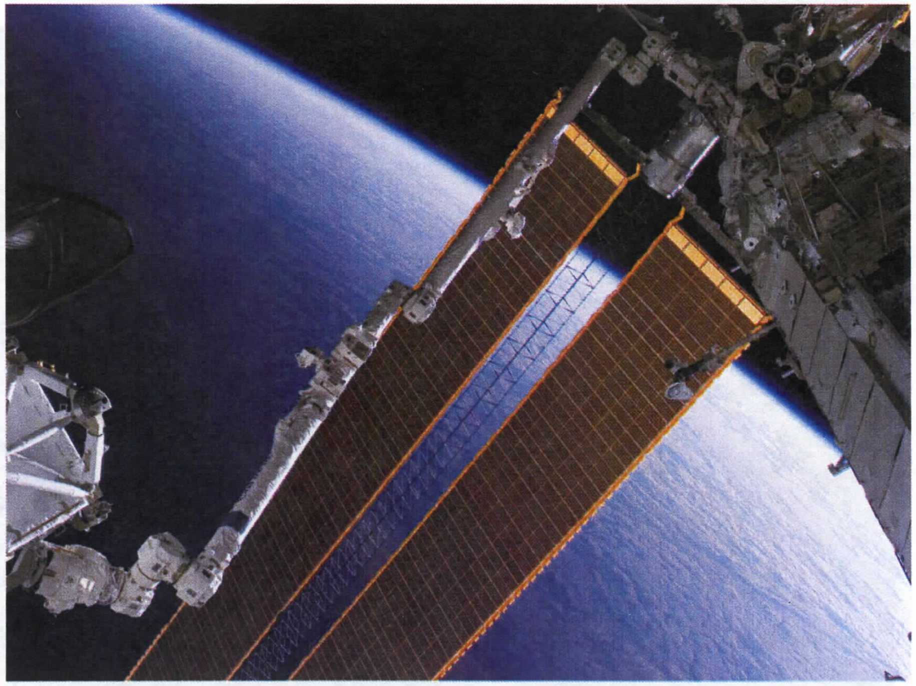






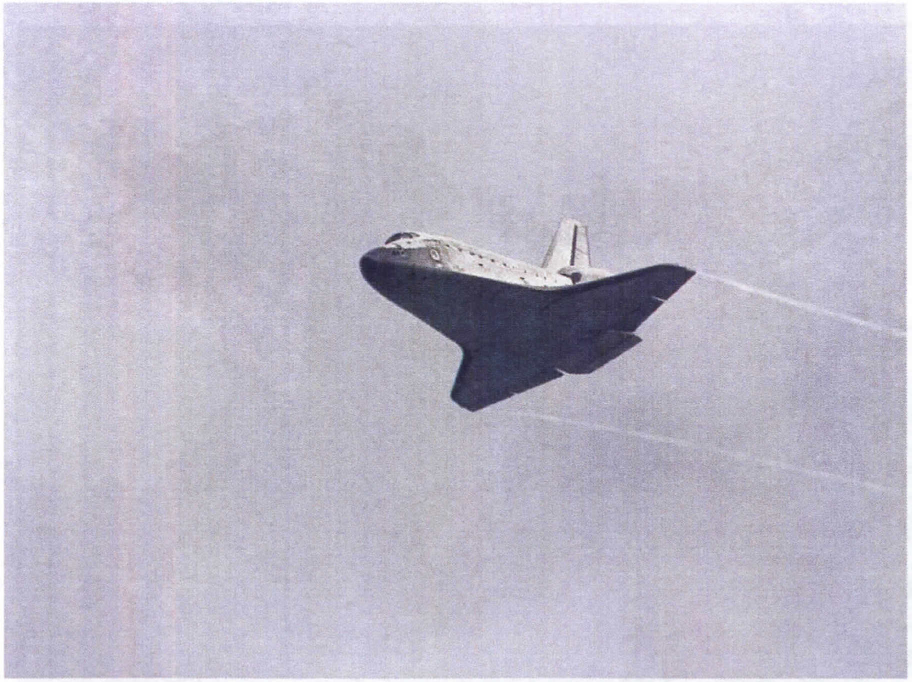


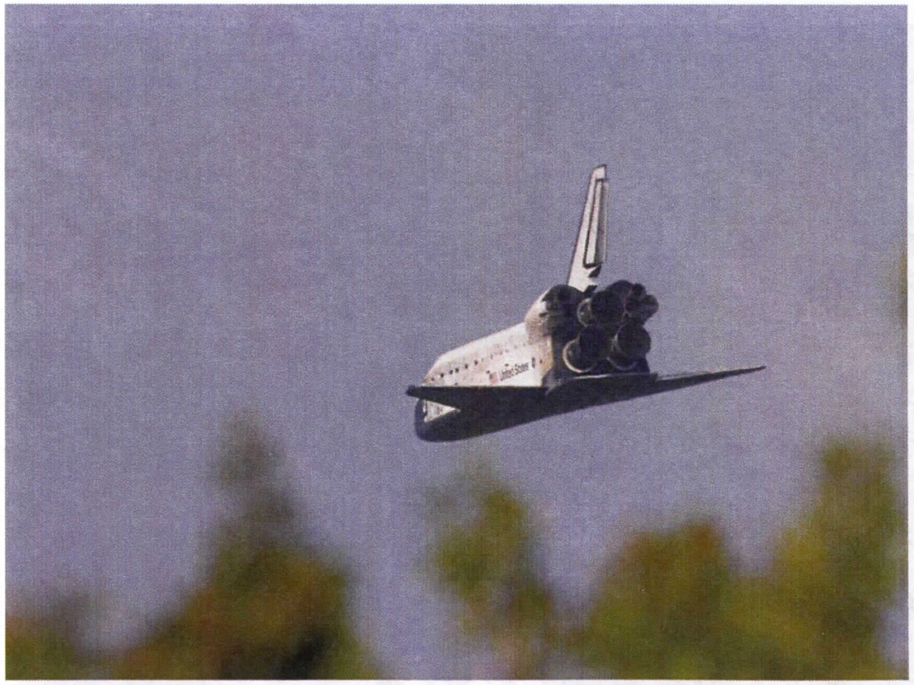

Discovery



Not all work and No Play…

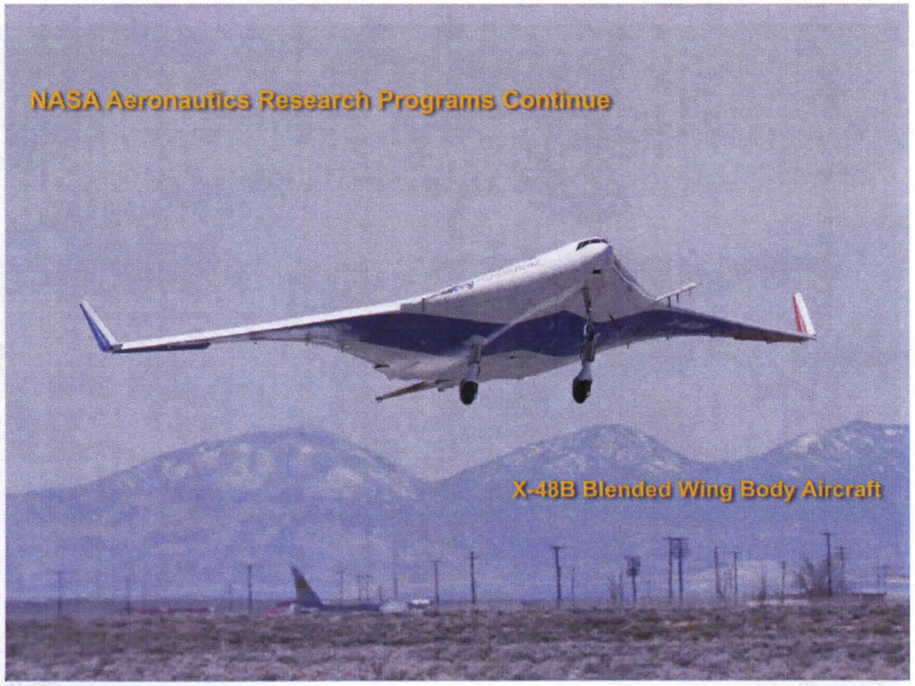
Discovery Returns





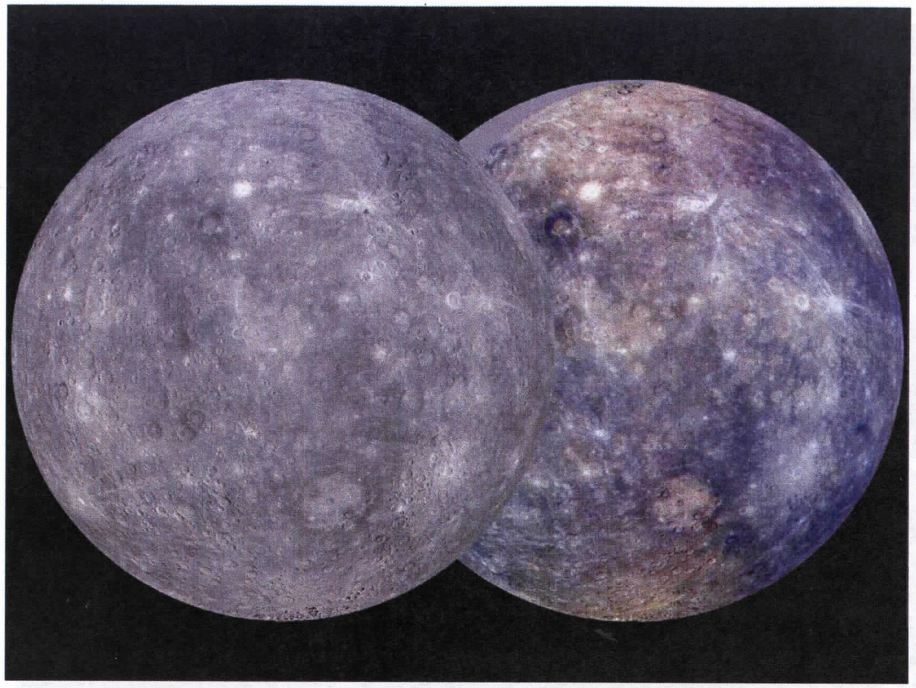

United States

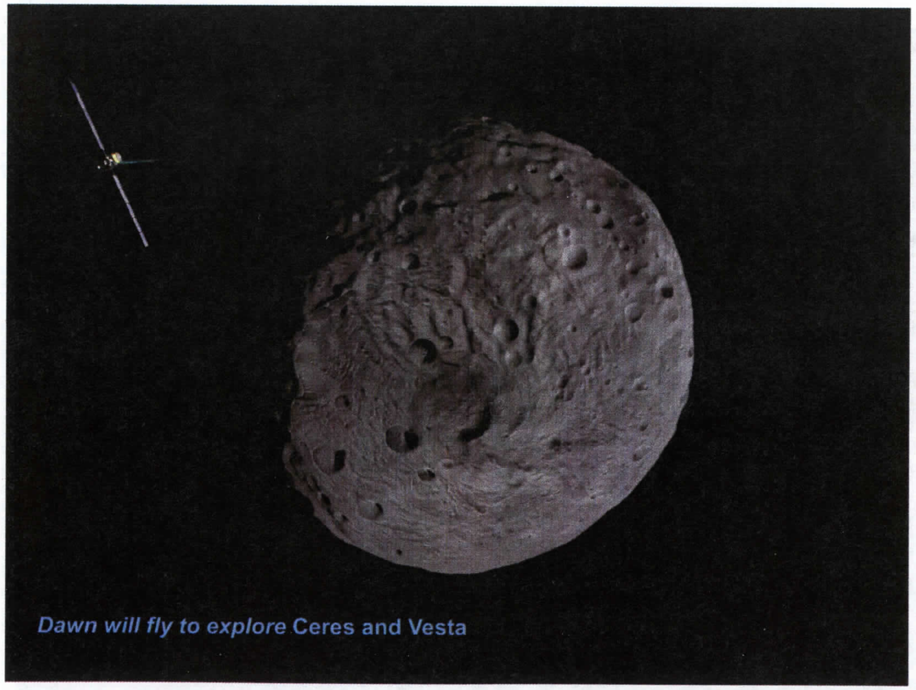

What's Next...
Mars
Asteroid
Moon
Orion MPCV

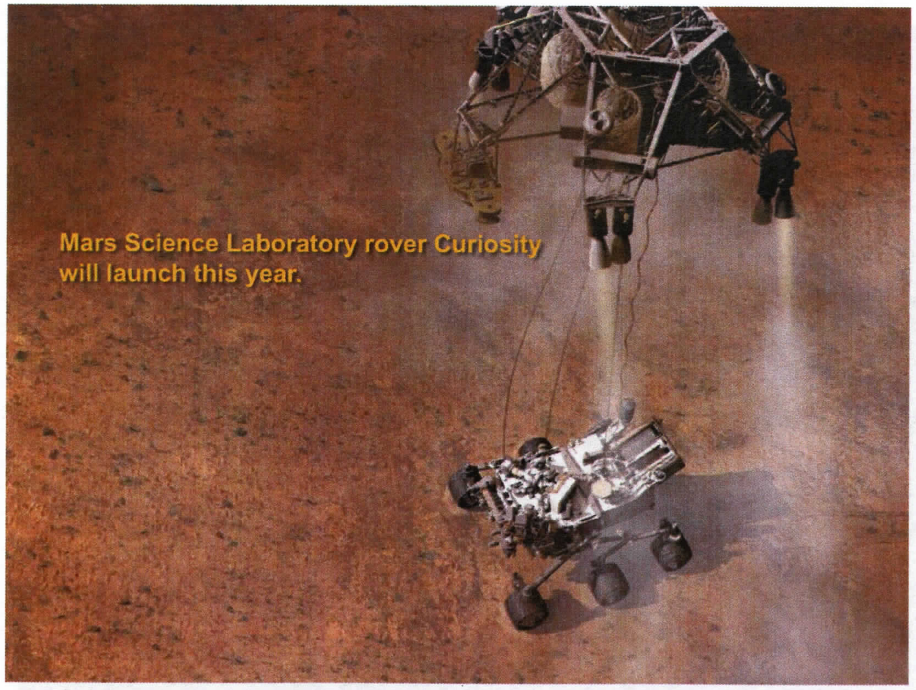

NASA Aeronautics Research Programs Continue
X-48B Blended Wing Body Aircraft

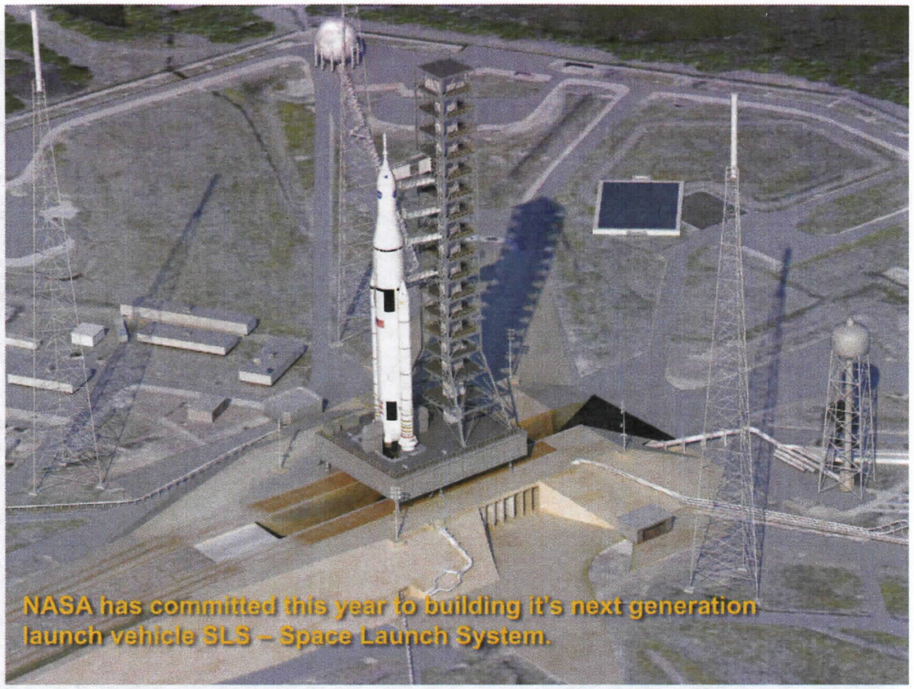

The International Space Station
continues operations

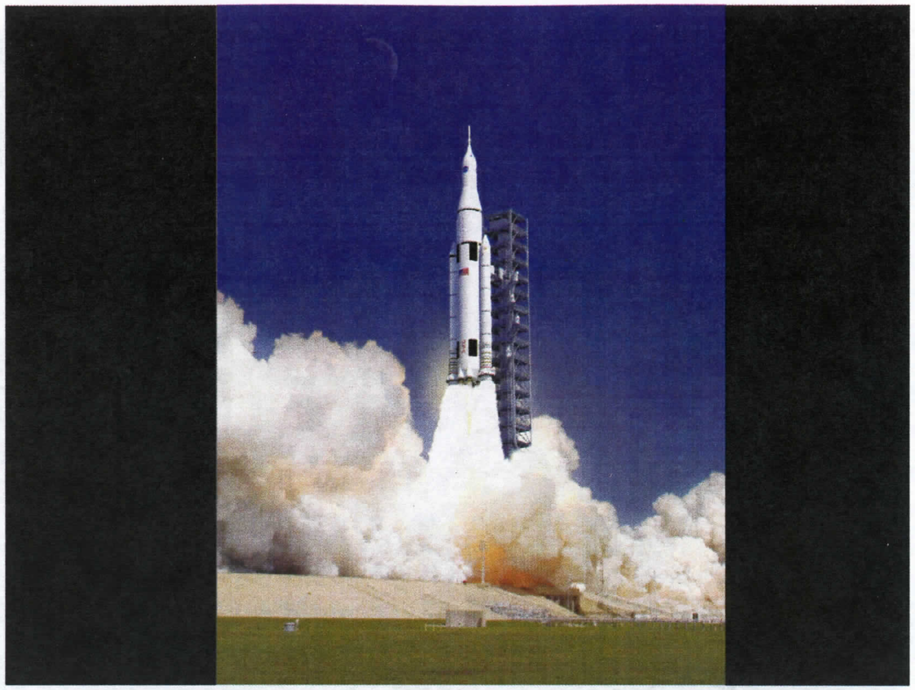

Spirit Remains Silent at Troy
Opportunity Past 21 Miles of Driving...
Will Spend Winter at Cape York

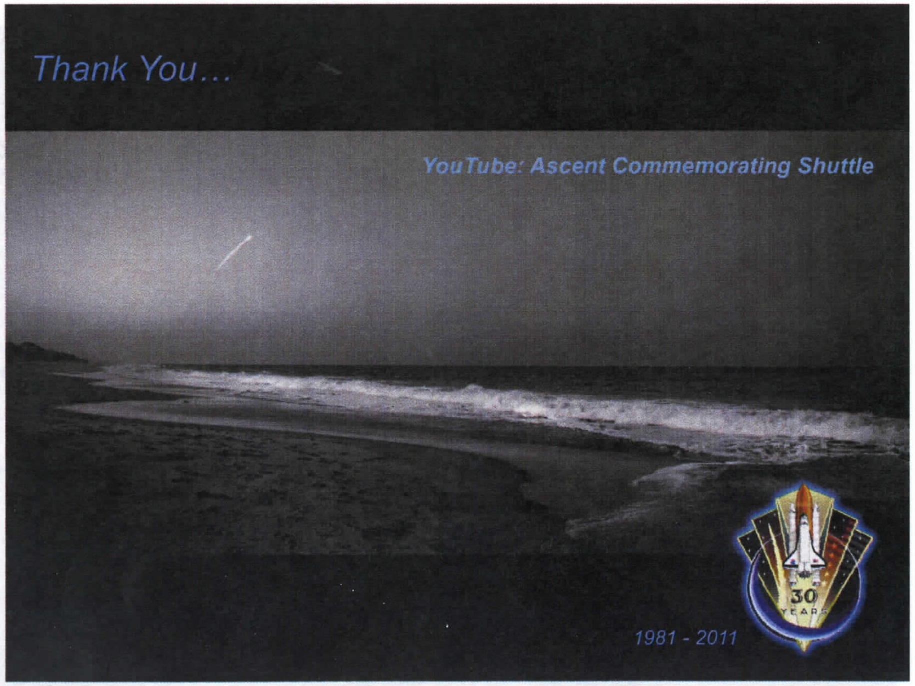



Dawn will fly to explore Ceres and Vesta


Mars Science Laboratory rover Curiosity
will launch this year.



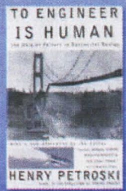




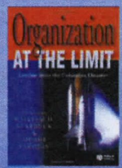
Additional Reading

- The Columbia Accident Investigation Board Final Report

- The Challenger Launch Decision by Diane Vaughan

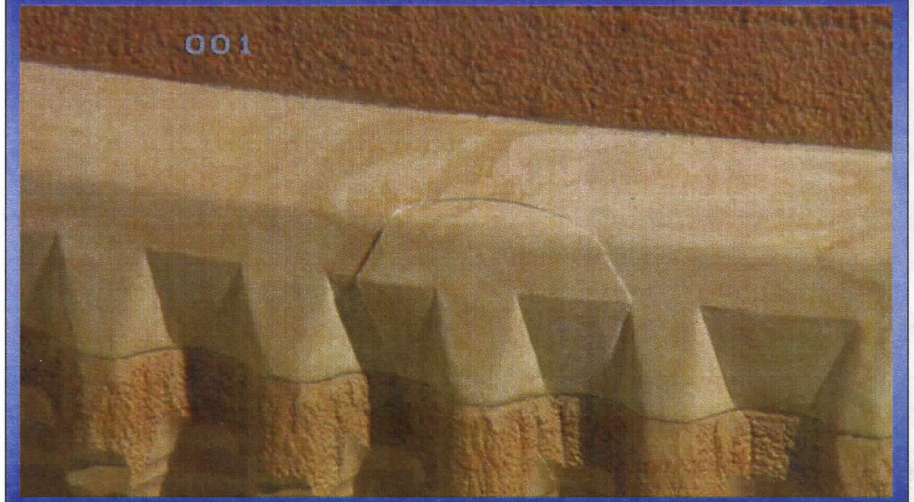


- To Engineer is Human by Henry Petroski



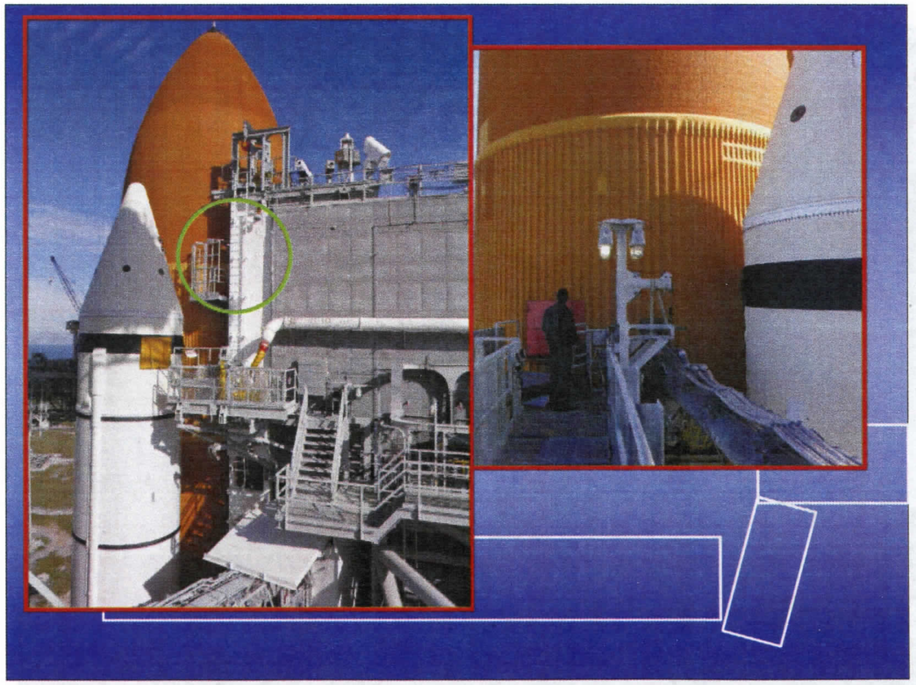
- Organization at the Limit by William Starbuck and Moshe Farjoun

- Lessons from Everest: The Interaction of Cognitive Bias, Psychological Safety, and System Complexity by Michael Roberto. Obtain from Harvard Business Online

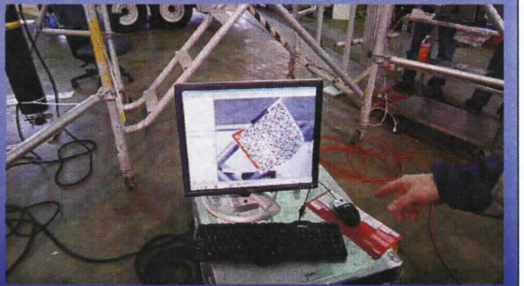


Foam failure at LOX intertank flange which Initiated Investigation

Repair on damaged foam will be first area of interest to be imaged during tanking with the Aramis system.



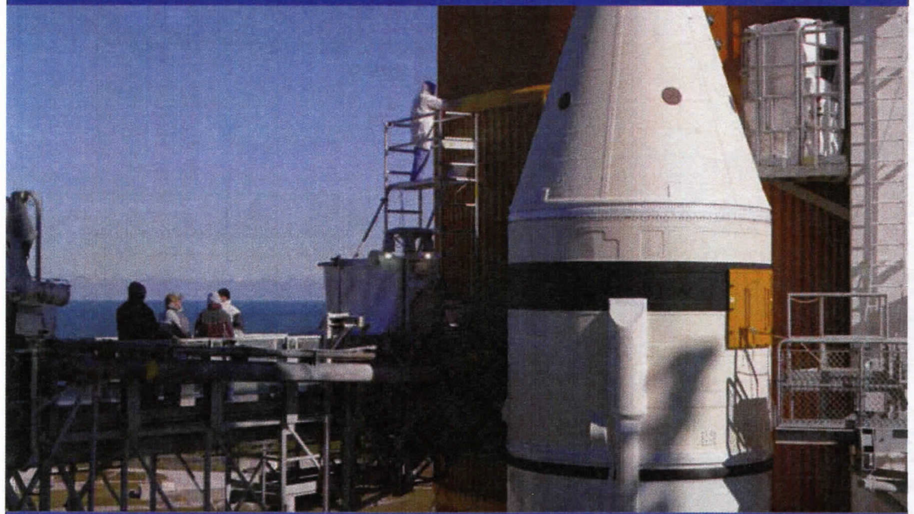
Two beams constructed from scratch on site (in hangar G) to set up two stereo camera system mounts to Shuttle fixed service structure at the 215 foot level to view two separate areas of interest on the external tank.



Dot pattern checks out for use on the tank

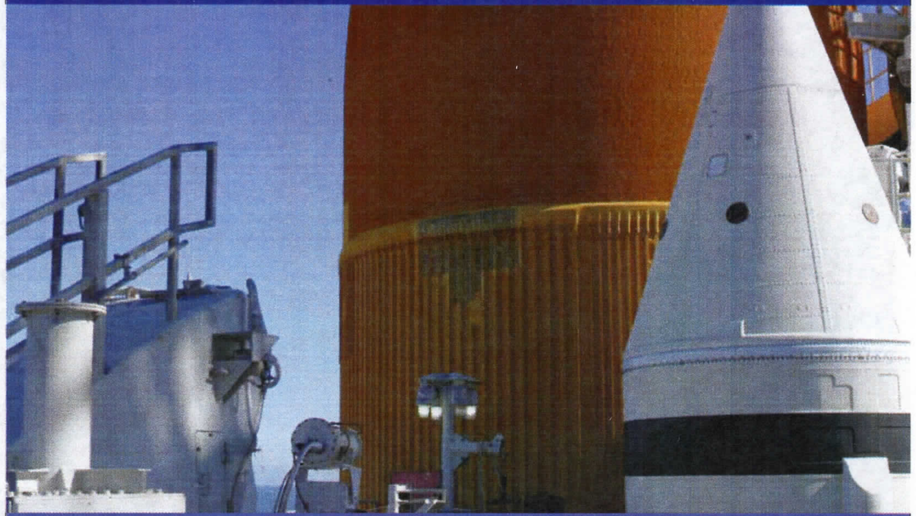
Two beams constructed from scratch on site (in hangar G – Air Force side of KSC) to set up two stereo camera system mounts to Shuttle fixed service structure at the 215 foot level to view two separate areas of interest on the external tank.

Shuttle technicians applying paint dots to one area of interest on tank

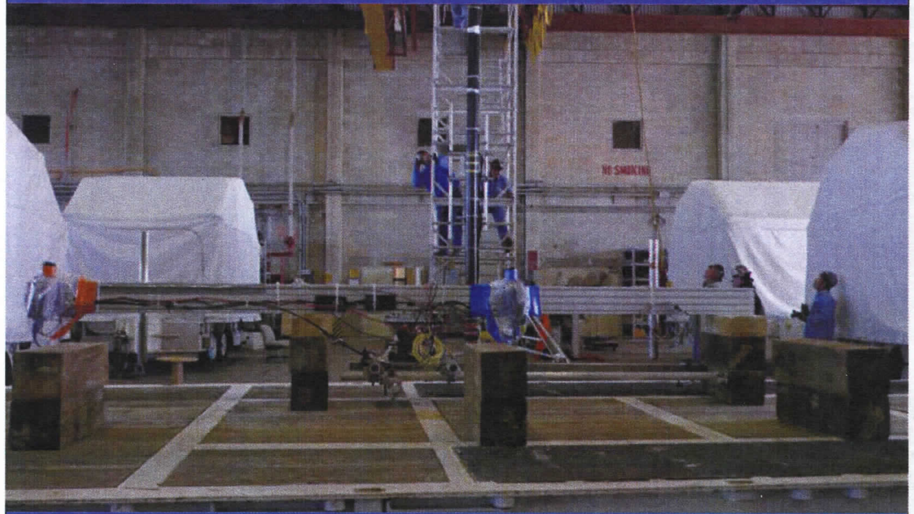


Shuttle technicians applying paint dots to one area of interest on tank

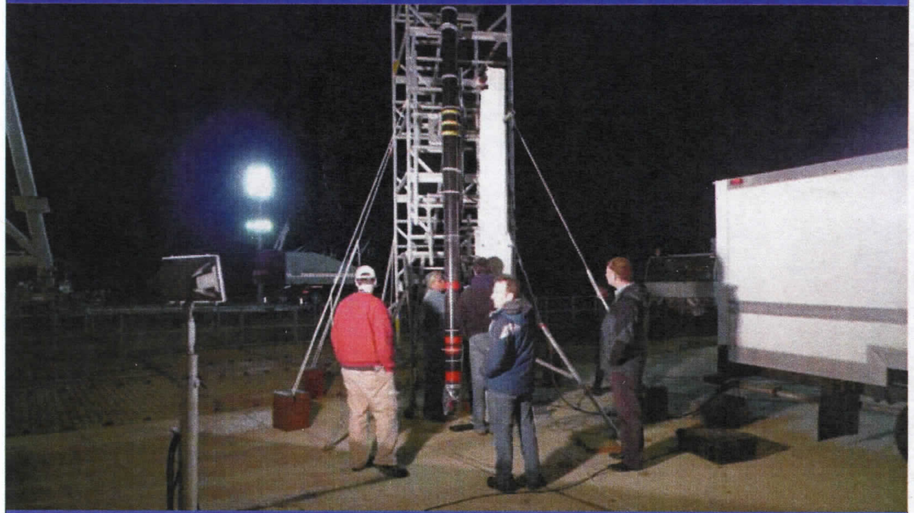
Shuttle technicians applying paint dots to one area of interest on tank



Paint dots successfully applied to Lox Flange area of ET



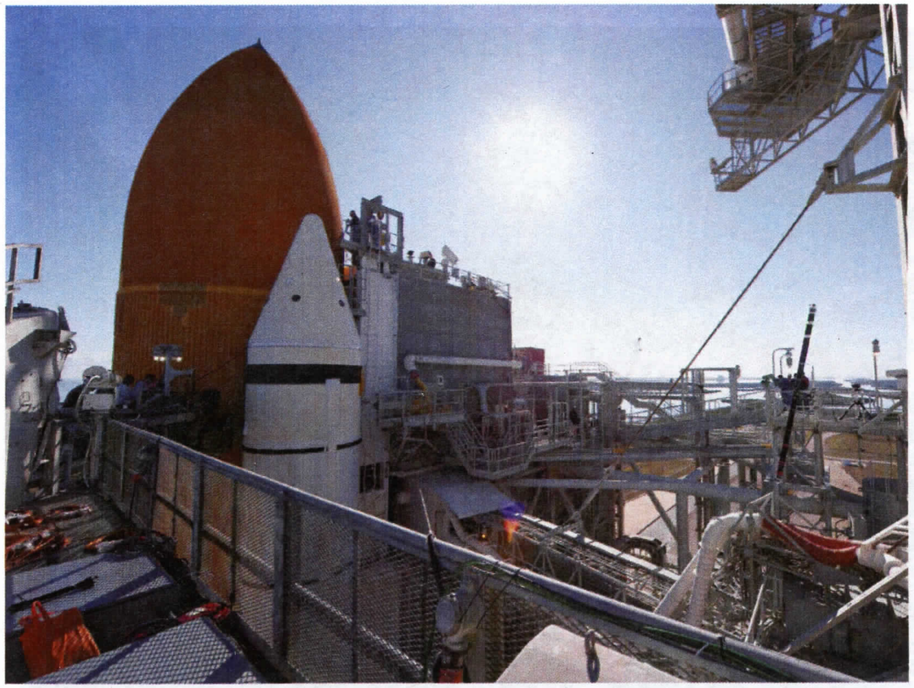
Calibrated beams in Hangar G ready for truck transport to Pad



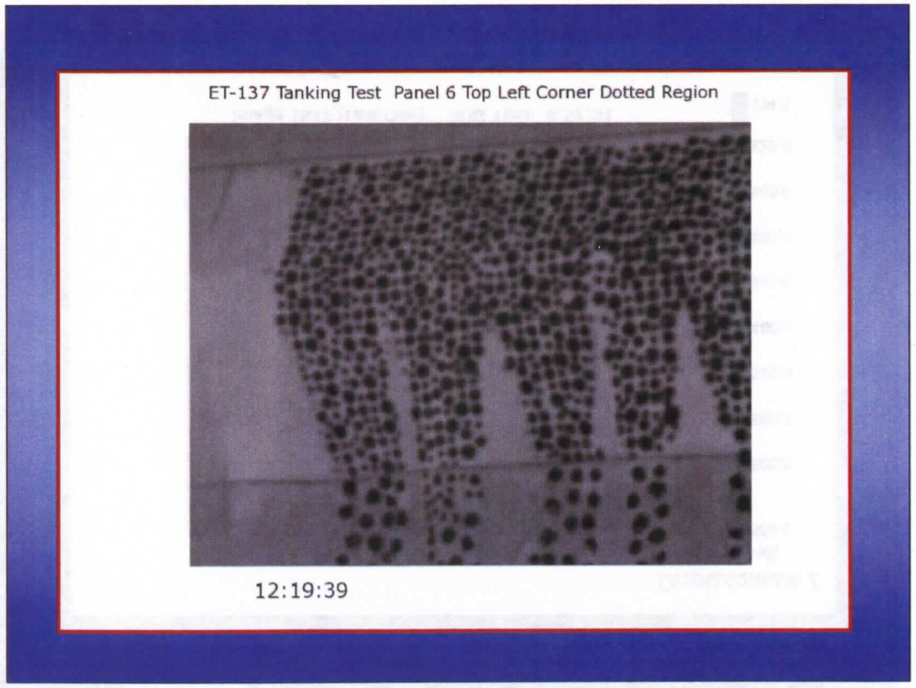
Calibrated beams reside at Pad ground level night before lift

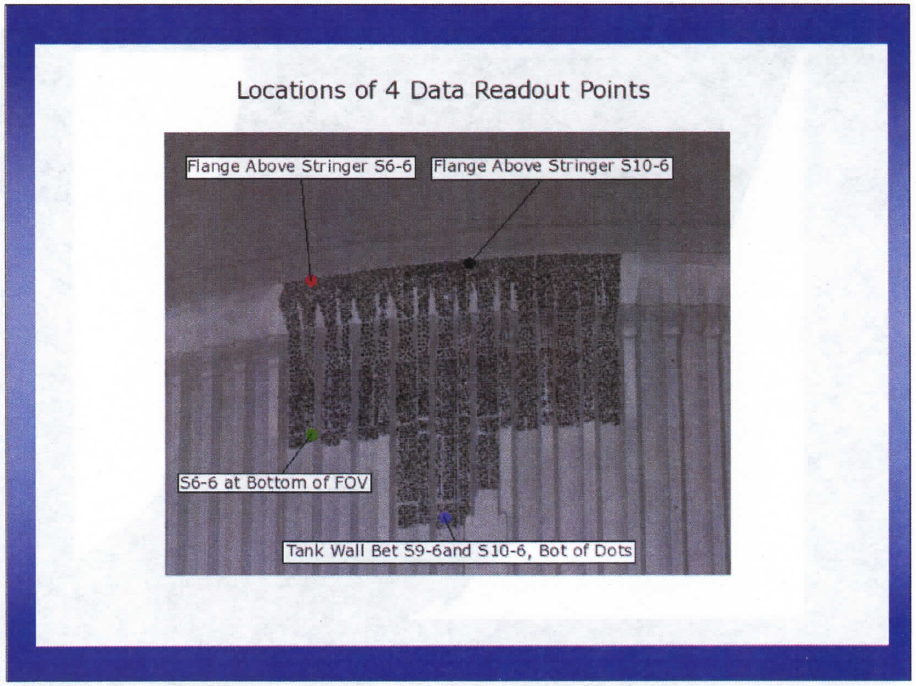
0530 hrs - Morning of lift on day before tanking test


TADANO

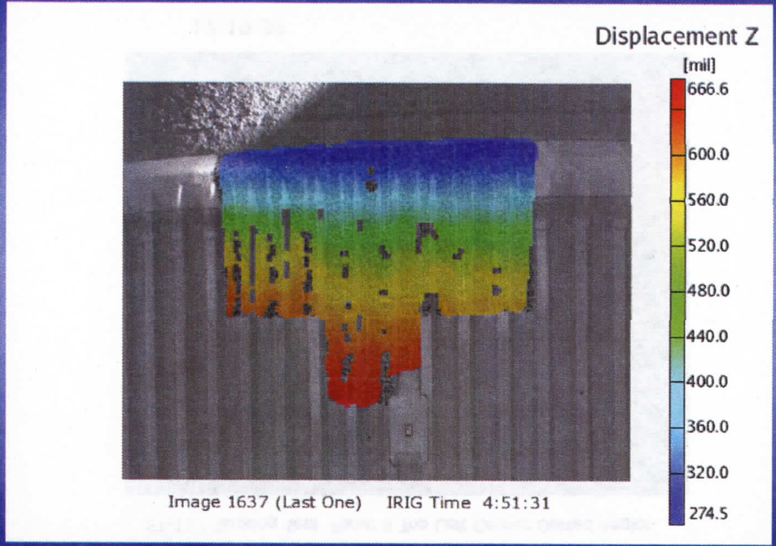



FLORIDA INSTITUTE

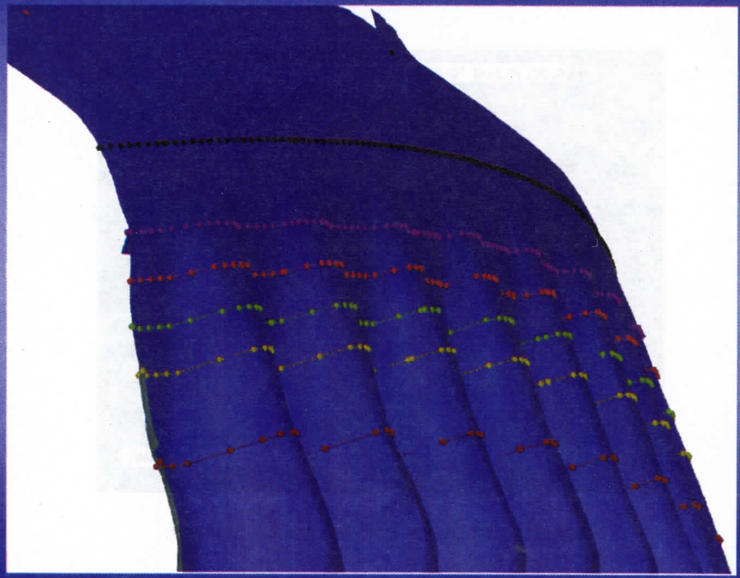

ET-137 Tanking Test Panel 6 Top Left Corner Dotted Region
12:19:39


Locations of 4 Data Readout Points
Flange Above Stringer S6-6
Flange Above Stringer S10-6
S6-6 at Bottom of FOV
Tank Wall Bet S9-6and S10-6, Bot of Dots

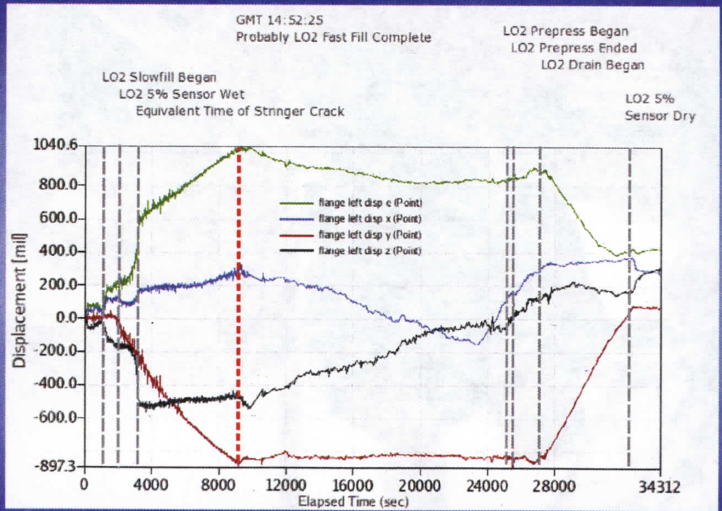
Out-of-Plane Displacements



Section lines on ET Panel 6



Timeline Information



Requested Milestones are Shown in Gray
Additional Milestone is Shown in Red
(LO2 Fast Fill Complete Was Estimated at 14:50 on USA Chart)